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# SHIP SYNTHESIS MODEL FOR COAST GUARD CUTTERS

Michael Jay Goodwin

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# SHIP SYNTHESIS MODEL FOR COAST GUARD CUTTERS

by

MICHAEL JAY GOODWIN

B.S., Webb Institute

1969

SUBMITTED IN PARTIAL FULFILLMENT

OF THE REQUIREMENTS FOR THE

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and

THE DEGREE OF MASTER OF

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Thesis
G 5977

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# ABSTRACT

Ship Synthesis Model for Coast Guard Cutters
by: Michael Jay Goodwin
Submitted to the Department of Ocean Engineering on
May 9, 1975, in partial fulfillment of the requirements
for the degree of Ocean Engineer and the degree of
Master of Science in Naval Architecture and Marine Engineering

In order to determine the optimum design of a Coast Guard cutter, it is necessary to perform a large number of feasibility studies. This is an impossible task if done using hand calculations. A mechanized version of these hand calculations is developed which will permit the calculations to be performed by a digital computer. The final program listing is given together with the development of the empirical relations used.

The program is applicable to search and rescue and patrol type cutters with lengths between 150 and 400 feet. Twin screw propulsion is assumed.

A check on the accuracy of the program is made using three U.S. Coast Guard cutters now in service and the U.S. Navy's Patrol Frigate design. The program is found to be much more accurate than existing programs when applied to Coast Guard vessels. The program predicts the full load displacement within four percent for the Coast Guard designs tried.

Thesis Supervisor: Clark Graham
Title: Associate Professor of Ocean Engineering

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# CHAPTER I

## INTRODUCTION

Although digital computers have been used by engineers for more than twenty years, their potential as design aids is only beginning to be realized. Naval architects made use of computers soon after they became available for solving specific algorithms such as displacement sheet calculations and speed-power estimates. Such algorithms are beneficial in the preliminary and later design stages. However, with the growth of systems engineering in ship design, more emphasis is being placed on the conceptual or earliest phase of a design. At this stage of the design, the computer can be used more effectively than at any other stage.

Because of the complexity of the naval architectural calculations involved in later design stages, the principle characteristics of a ship must be chosen early in the design. The output of the conceptual design phase is this set of characteristics. Without the use of a computer, the best that can be done is to develop a feasible set of characteristics when a optimum set is desired. Systems engineering is placing more emphasis on obtaining this optimum.

To choose an optimum or near optimum set of characteristics, a great many feasibility studies are required. It

is impossible to do more than a few feasibility studies without the aid of computerized models because of the time required. At this early stage, the ship must be designed as a whole. This precludes dividing the work into a number of parallel paths with several people working simultaneously on a single feasibility study. Each study is essentially a one man job.

With hand calculations a good engineer can perform about one feasibility study per day. As a result, great reliance must be placed on the designers intuition. In the past this has led to series of designs which may or may not have been optimum. Each new design was a slight perturbation of a previous successful design. While this procedure produces satisfactory designs, bad features tend to be duplicated and few new features are added. The engineer was not really at fault because no tool was available to perform all the calculations necessary to obtain an optimum design.

Computers permit the mechanization of these hand calculations. The software required will be referred to here as a ship synthesis model. The model aids the designer by freeing him from the routine calculations which take up most of his time during the early phases of design. The algorithms referred to previously also free the designer from tedious calculations.

What makes a ship synthesis model different is that it goes beyond merely reducing the time and effort required

to do calculations previously done by hand. Using the model, hundreds or even thousands of feasibility studies can be made. While this still does not guarantee that the optimum solution is obtained, the engineer will have much more confidence in his design than he would if only a few feasibility studies had been made. The designer is free to concentrate on the more important aspects of the early stages of ship design such as systems level tradeoff decisions. These include hull form, speed, endurance and payload options among others. These aspects were seldom considered in detail before the advent of ship synthesis models.

Equally important is the fact that computers permit a consistency among feasibility studies. With several people doing independent feasibility studies or even with a single person doing them all, it is difficult to insure that the same assumptions will be made for each study and that no bias is applied. The model guarantees consistency. And consistency is important because without it two feasibility studies can not be compared and an optimum solution is difficult to select.

Several models have been available for a number of years and have proven their value. The U.S. Navy's destroyer model, DD07[(1)]*, on which the program developed in this thesis is patterned, was started in the 1960's

* Numbers in parenthesis refer to References at the end of this thesis

and updating work has been continuing since then. This was the first true "systems" model. Models also have been developed which attempt to model all surface ship types with a single program. For accurate results, each different ship type really requires its own model.

In addition to the destroyer model, the U.S. Navy has developed individual synthesis models for aircraft carriers, underway replenishment ships, submarines, hydrofoils, and several other ship types. The U.S. Coast Guard presently has no model which gives good results for cutters. The destroyer model, DD07, does not apply to ships as short as 150 feet in length which is one Coast Guard requirement. Some all inclusive models have been tried but with poor success, with predictions of displacement as much as 30 percent off when data on existing designs is inputed.

The program, which will be referred to as the cutter model, developed in this thesis is an attempt to satisfy the Coast Guard's need. The cutter model applies to search and rescue and patrol type cutters with lengths between 150 and 400 feet. It is not applicable to buoy tenders, tugs or ice breakers. An effort has been started by the Coast Guard to develop a model for buoy tenders and tugs but this work is not yet complete.

Even in the early stages of design where the synthesis models are of use, a great many calculations are required to prove the feasibility of a ship design. This has led designers to employ a type of regression analysis where

data from existing ships is scaled up or down in order to estimate values for a new design. This estimation procedure is employed in ship synthesis models also. More detailed calculations could be made but at the cost of greatly increased computer time since a large number of feasibility studies will be run.

The shortcut estimating techniques employed place more emphasis on the relative accuracy among studies rather than on the absolute accuracy of the result. Because of this, all estimating relationships in the model must show the dependence of the result on all significant input variables. At present, this is an impossible task because not enough is known about this dependence. As models become more widely used much development work will have to be done in this area. An estimate of the variation with the most significant input variable is the best that can be done at present.

Because the estimating relationships are rather crude, estimates are only made at the ship system level. Ship system level information consists of such elements as total outfit weight, total volume required for machinery and required electrical load for ventilation. Although total arrangements area is computed, no attempt is made to perform an arrangement of spaces or to compute trim. The engineer usually has sufficient flexibility in these areas to arrive at a feasible design if sufficient space is available.

One problem in developing a model for Coast Guard cutters is that there are few designs available from which to obtain data. This causes difficulty in determining rational scaling laws. In many cases the use of naval architectural principles indicates the correct scaling procedure. In other cases all that can be done is to search for the most logical correlation.

The design produced by a synthesis model should be tailored to meet the conditions required of a feasible solution. First there must be a balance between weight and displacement. Second, internal space available must equal internal space required. This requirement is becoming very important as most Coast Guard vessels are volume rather than weight limited. Third, the energy available must equal the energy required. This includes both propulsion and electrical power requirements. Finally, the distribution of weight and volume must be such as to satisfy design criteria for transverse stability, girder strength and sea keeping. There are also other requirements implicit in the solution such as hull type, material of construction and space requirements.

In general, the inputs required for a ship synthesis model are a description of the "payload" to be carried, a statement of vehicle mobility performance and a selection of options to be used. The payload description must be more detailed than a simple weight breakdown. The relative vertical centers of gravity, area requirements, electrical

power requirements and cost must also be given. Payload for the cutter model also includes people, and thus the size of the crew is an input. The description of vehicle mobility performance includes both maximum calm water speed and endurance speed and range requirements. Options include length, $C_p$, $C_x$,* as well as machinery type and margins. There is also an option in the cutter model to input the maximum sustained horsepower, in which case the program will calculate the maximum sustained speed. A full description of the program inputs for the cutter model is contained in Chapter III (Main Program Description) and in Appendix A.

The output generated by the model must be sufficient to demonstrate the feasibility of the design. Wherever possible, the output should permit the designer to verify the feasibility without doing additional calculations. On a few of the studies run and in particular on the design selected, the design team will have to lay out a rough arrangements drawing to verify that sufficient space is available. Sufficient information should be given in the output to permit this to be done easily.

The output generated should also allow the designer to rapidly determine the design that best satisfies his optimization criterion. This criterion usually takes the form of a total acquisition cost or life cycle cost.

*The definition of coefficients and dimensions used in this thesis may be found in Reference (3).

Predictions of acquisition cost are often included in a ship synthesis model.

Finally, the output should provide a basis for beginning the preliminary design phase. Generally the preliminary phase is handled by a number of design teams working in parallel. The output produced must provide information to initialize each of these parallel developments.

Sample output listings for the cutter model are given in Appendix B.

It is important to emphasize that the cutter model produces a feasible solution only and not an optimum solution. An optimum solution implies that the best of a very large number of feasible ships has been chosen. It is felt that the design process works more efficiently if the designer acts as a guide for the computer rather than having the computer do the entire optimization on a single run. In this way, many unnecessary designs can avoided in areas where designs are less attractive than others already tried. Such a process takes more real time but less computer time. It also gives the designer a much better feel for the sensitivity of the optimum to changes in characteristics.

The remainder of this thesis is arranged as follows:

Chapter II gives an overview of the cutter model and explains the major options.

Chapter III goes into detail on each of the sub-routines in the model and explains the derivation of all

of the empirical formulas used. This chapter may be skipped by anyone not interested in the details of the program.

Chapter IV gives an evaluation of the model including test runs made using existing ships.

Chapter V contains recommendations and conclusions.

Appendices A and B contain input and output formats respectively.

Appendix C is a listing of the program.

The remaining appendices give background information used in this work.

It is recommended that at least Chapters I, II, IV, V and Appendix A be read before attempting to use the program. Chapter III is aimed primarily at the person who wishes to modify the program. However, the important aspects of each subroutine are covered in the introduction to each of the subsections of Chapter III.

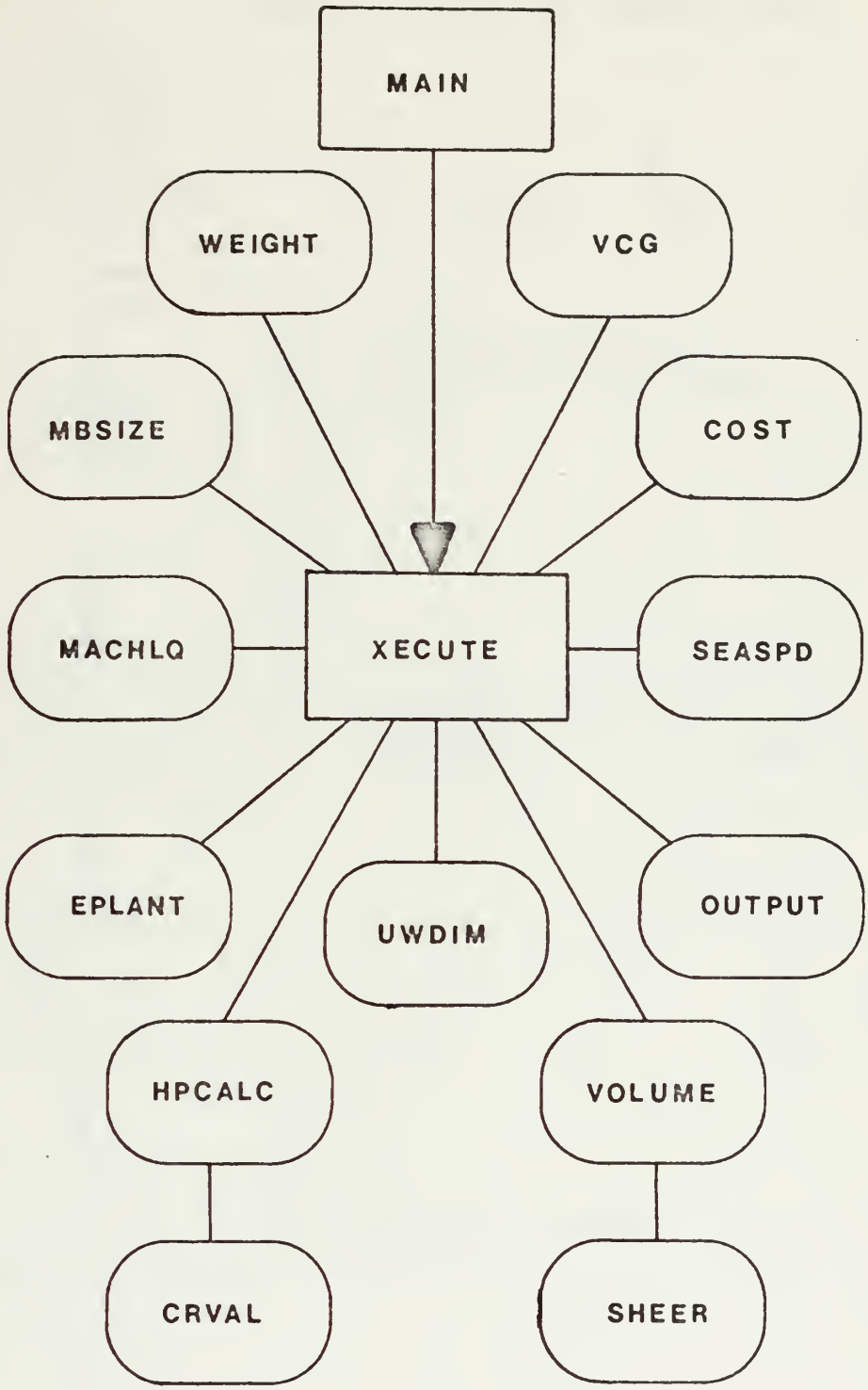
# CHAPTER II

## GENERAL PROGRAM DESCRIPTION

This chapter gives an overall description of the solution method used by the cutter model but does not discuss the detailed calculations. The detailed calculations are explained in Chapter III. This chapter should also serve as a guide to understanding how each subroutine discussed in Chapter III fits into the total program.

The organization of the computer program can be viewed in two different ways. The first is the program control organization which is shown in Figure 1. Subroutine XECUTE controls the entire solution of each feasibility study case. Control is returned to the main program only when data for a new case is required. Subroutine XECUTE calls other subroutines as needed and gradually fills all the data storage locations needed for output. This subroutine also controls the iteration loops for weight and vertical center of gravity.

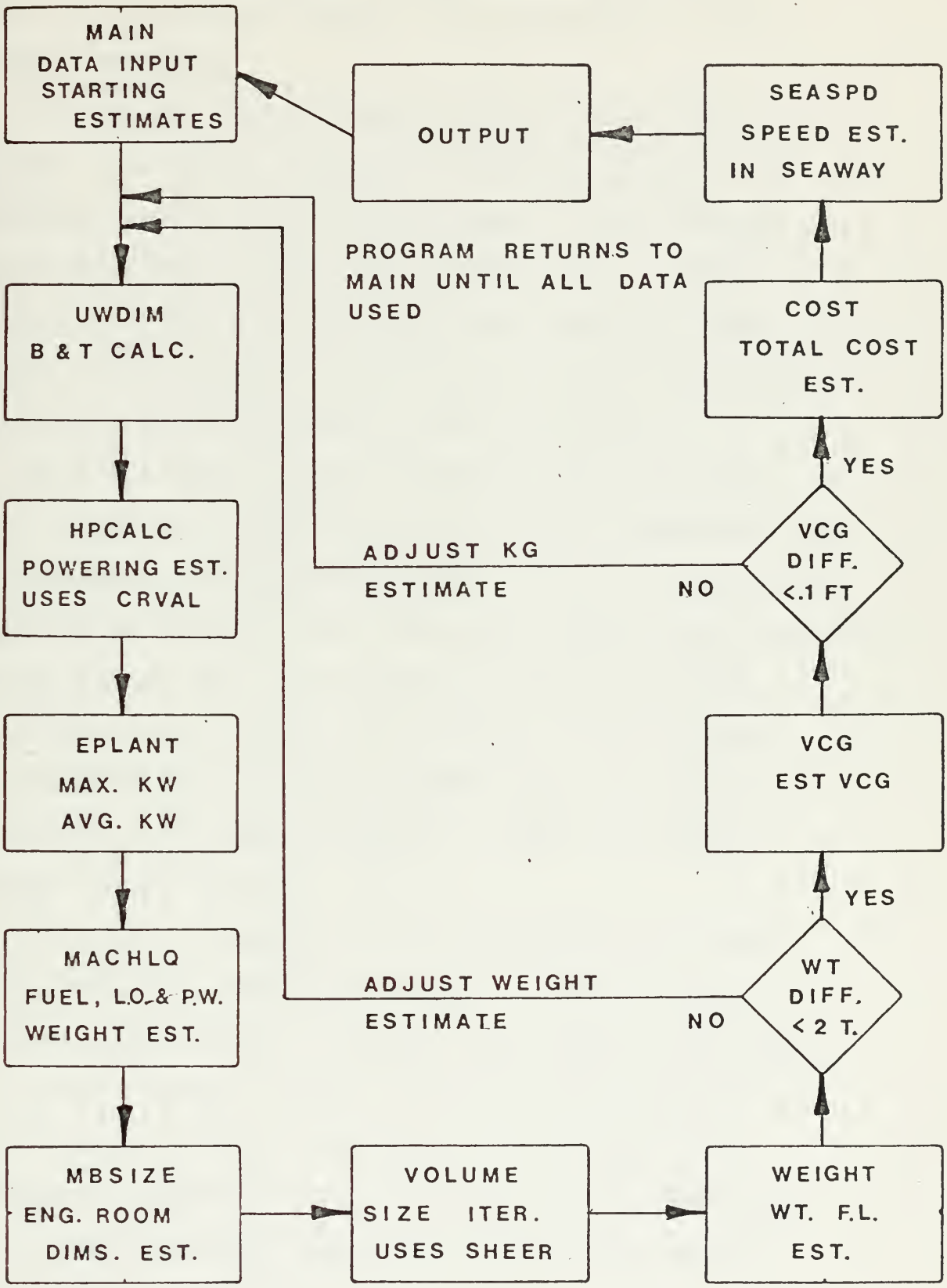
The logical organization of the program is shown schematically in Figure 2. This is an easier organization scheme to follow and shows more clearly how the program solves each input case. It will be noted that subroutine XECUTE has not been shown in Figure 2. As explained above, XECUTE merely guides the computer around the




PROGRAM CONTROL ORGANIZATION

Figure 1

Figure 2
LOGICAL PROGRAM ORGANIZATION



logical organization chart. Error messages are also printed by subroutine XECUTE if any constraint of the model is violated.

The program begins with data input in the MAIN program. The primary purpose of the MAIN program is to read data cards and all input is done in this routine. Some bookkeeping is also done in MAIN such as summing payload weights and costs. The final purpose of this routine is to estimate initial values of vertical center of gravity, KG; displacement, and cubic number.

Once all data for one feasibility study has been read by MAIN and the initial values of KG, displacement and cubic number have been determined, control is transferred to subroutine XECUTE. This subroutine directs the execution of the program until a solution is obtained or until a constraint is violated. When either of these occur control reverts to the MAIN program where data for the next feasibility study is read. If there is no more data the program stops.

The first subroutine called by XECUTE is an underwater dimensions subroutine, UWDIM. Subroutine UWDIM uses the input values of length, free surface correction, $C_p$, $C_x$ and GM/Beam as well as the estimated KG and displacement to calculate the required beam, draft and waterplane coefficient, $C_{wp}$. To the level of accuracy of this program these completely determine the underwater shape of the hull.

Two options are available with regard to speed and power calculations. Under the first option the maximum sustained speed of the vessel is input. If this option is specified, XECUTE calls subroutine HPCALC which, together with subroutine CRVAL, estimates the horsepower required to maintain the maximum sustained speed.

Option two allows the user to specify the maximum sustained horsepower. In this case the program will compute the maximum sustained speed. Subroutine HPCALC has been written to take speed as an input and return a value of horsepower. Therefore, an iterative procedure is required if this second option is used. Control of this iteration takes place in subroutine XECUTE.

Regardless of which of the above options is used the endurance speed is input. Subroutine HPCALC is called to determine the power required at endurance speed.

A Taylor Standard Series horsepower estimate is used in subroutine HPCALC. Stored values of $C_r$ are used. The purpose of subroutine CRVAL is to choose the correct $C_r$ value from a stored array. Reference (7) explains this method for estimating horsepower.

The electrical power routine, EPLANT, is the next one called. This routine determines the maximum electrical load at sea, the average electrical load and sizes the generators. The average load is needed for estimating generator fuel consumption. The input electrical loads along with crew size and cubic number are used in this

routine.

The weight of fuel, lubricating oil and potable water is next calculated in subroutine MACHLQ. The endurance range given as input together with crew size and the endurance power calculated earlier are used by this routine. Lub oil requirements are either input, in the case where horsepower is specified, or are estimated based on specified machinery type. Potable water requirements depend entirely on the crew size. If make-up feed water is required it should be specified as a cargo load item. The specific fuel consumption is either input, in the case where horsepower is specified, or is estimated based on machinery type and horsepower.

Subroutine MBSIZE is next called if the sustained speed is specified. This routine estimates the machinery box length and minimum depth. If the horsepower input option is specified these dimensions are input.

The next subroutine is one of the most important in the program. Subroutine VOLUME determines both the sheer line and the deckhouse volume. These complete the definition of internal volume and arrangements area since the underwater volume has been determined in subroutine UWDIM. Because most ships for which this program applies are volume rather than weight limited, it is important to insure that there is sufficient space for all ship functions and equipment which must be installed.

The volume is divided into three categories. First,

there is the engine room. The dimensions for the engine room have been estimated earlier. Second is tankage volume and finally arrangements volume. Arrangements volume is more useful if converted to an arrangements area.

As a first step in determining the space available in each of these categories, the sheer line must be determined. Subroutine VOLUME calls subroutine SHEER to determine an acceptable sheer line. The sheer line must meet several criteria including adequate freeboard forward and aft, adequate depth amidships for the engine room and for adequate strength, and an acceptable sheer line curvature.

With the sheer line fixed, the total volume of the hull is estimated. The volume of the engine room is also estimated and then subtracted from the total volume. Next, an estimate is made of the fraction of the remaining volume which can be used only for tankage because it is unsuitable for use as arrangements volume.

A required tankage volume is then estimated based on the weights of fuel, lub oil, potable water and aircraft fuel. This required tankage volume is compared to the volume which must be used for tankage. The larger of the two is subtracted from the hull volume that remains. The remaining hull area is available for use as arrangements volume. This volume is converted into an arrangements area.

A required arrangements area is computed based on

empirical data from past designs and on input area values. By adjusting the size of the superstructure or by adding a raised deck, the available arrangements area can usually be made to equal the required arrangements area. If too large a deckhouse is required or if a raised deck longer than the length of the ship is needed, an error message is generated and a new input case is tried.

Once the volume of the hull has been determined, the weight of all the light ship weight groups and of the load items can be calculated. This is done in subroutine WEIGHT. Although many of the items calculated by this routine are later printed as output, the variable of immediate importance is the full load weight, WFULLD. This value is compared with the initial guess of displacement. If there is a difference of greater than 2 tons between the two, a new estimate of displacement is made and the program returns to subroutine UWDIM for a new estimate of dimensions. Once a balance between WFULLD and displacement is achieved the program proceeds to the estimation of vertical center of gravity.

Subroutine VCG makes this estimate. Most centers are taken as a fraction of the average depth of the hull or of the amidships depth. The estimated vcg is compared to the initial guess and a new KG estimate is made if there is no agreement within a tenth of a foot. Once a balance is obtained, the program proceeds to a cost estimate.

The lead ship cost is estimated using a Coast Guard cost estimating procedure known as "Flanagan's Method"(6) This procedure has been programmed as subroutine COST.

An estimate of the speed the vessel will be able to sustain in the North Atlantic Ocean is made in subroutine SEASPD. This routine is based on work done at the Naval Ship Engineering Center as reported in References (4) and (5).

Finally, subroutine OUTPUT is called. The purpose of this routine is to print the values determined by the other routines. The input data is also printed so that a compact record of the feasibility study is produced. After the output is printed, the program returns to the MAIN program to read more data and start a new case.

This concludes the general description of the program. A much more detailed description is given in Chapter III. The reader who is not interested in the details of the program can skip Chapter III with no loss of continuity.

# CHAPTER III

# DETAILED DESCRIPTION OF THE PROGRAM

## 3.1 Introduction

This chapter is composed of sixteen sections including this introduction. The other fifteen sections each explain in detail one subroutine of the cutter model. For the location of these subroutines in the overall program refer to Figure 2, Logical Program Organization.

An attempt has been made to keep each section in the same format. A brief description of the routine will be given first followed by a list of required inputs. Statements will then be explained one by one. A list of the outputs produced by the subroutine will be given next. Finally, a nomenclature list will be given. The nomenclature list applies only to the subroutine being considered. In some cases the same variable will have different names in different subroutines.

In both the input and output listings a code is employed to indicate whether the variable is transferred by a labeled common statement, LC(AA), or as a subroutine call dummy argument, SCDA. The letters in parenthesis after the labeled common code indicate which labeled common was used to transfer the argument.

## 3.2 MAIN Program

### 3.2.1 Introduction

The MAIN subroutine performs several functions. First and most important is the reading of all input data used by the model. Each feasibility study case starts with the reading of one or more data cards by the MAIN program. The actual execution of each case is controlled by subroutine XECUTE. This routine is discussed in Section 3.3. However, once execution on a case is complete, control is returned to the MAIN subroutine. A check is then made to see if there is more input data. If not the MAIN subroutine directs the computer to stop.

Several bookkeeping tasks are performed in this subroutine also. These include such jobs as adding together the deck area and electrical load requirements of the individual payload items. The final function performed is the setting of initial values for displacement, KG and cubic number. These values are used for the first iteration and are then replaced by better estimates.

### 3.2.2 Inputs

Block Data subroutines have not been used in this model. As a result there are no variables with assigned values at the beginning of the MAIN program. All of the variables required are read from data cards or assigned values in the routine.

A flow chart for this routine is given in Figures

3a and 3b. A listing of the program is given in Appendix C. The nomenclature list at the end of this section gives a description of each variable name used.

3.2.3 Statement Descriptions

A line by line discussion of the program statements follows. The REAL and COMMON statements have not been listed but may be found in Appendix C.

REAL Statements - An explicit type definition has been employed so that the variable names will be more descriptive of their actual meanings.

COMMON Statements - Because a great many variables are required to define each case, COMMON statements have been used to transfer values between subroutines. This also saves computer storage space. All COMMON statements used are labeled common.

$C_r$ array input:

```
      READ(8,120) CR1
  120 FORMAT(16F5.0)
      READ(8,121) CR2
  121 FORMAT(9F5.0)
      READ(8,122) CR3
  122 FORMAT(6F5.0)
```

The three arrays which contain the Taylor's Standard Series $C_r$ values are read only once at the beginning of the program.

INDEX input:

```
    2 READ(8,124) INDEX
  124 FORMAT(I1)
```

The variable named INDEX has two functions. First, as described below, it tells the program when to stop.

# MAIN SUBROUTINE FLOW CHART

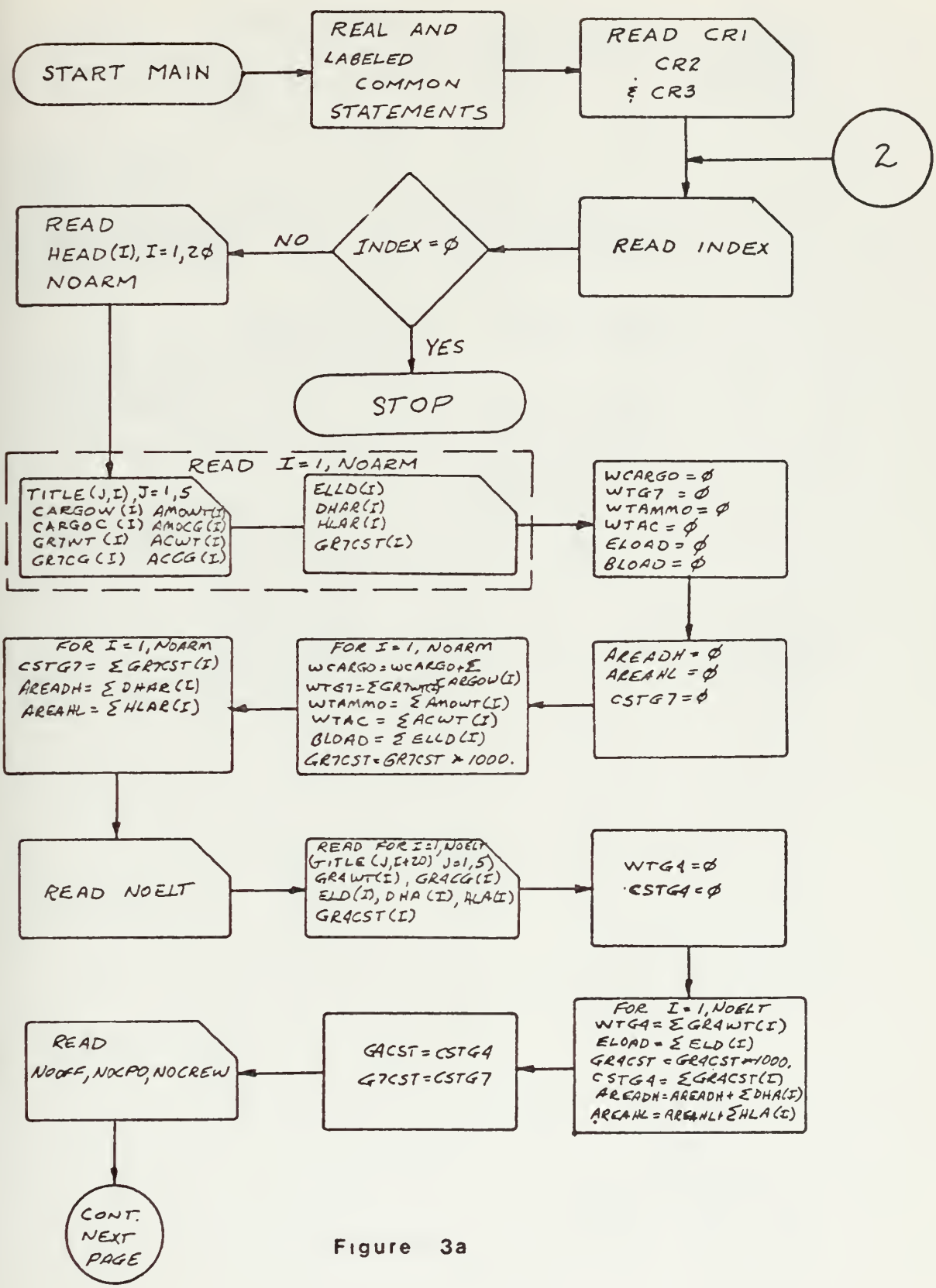



Figure 3a

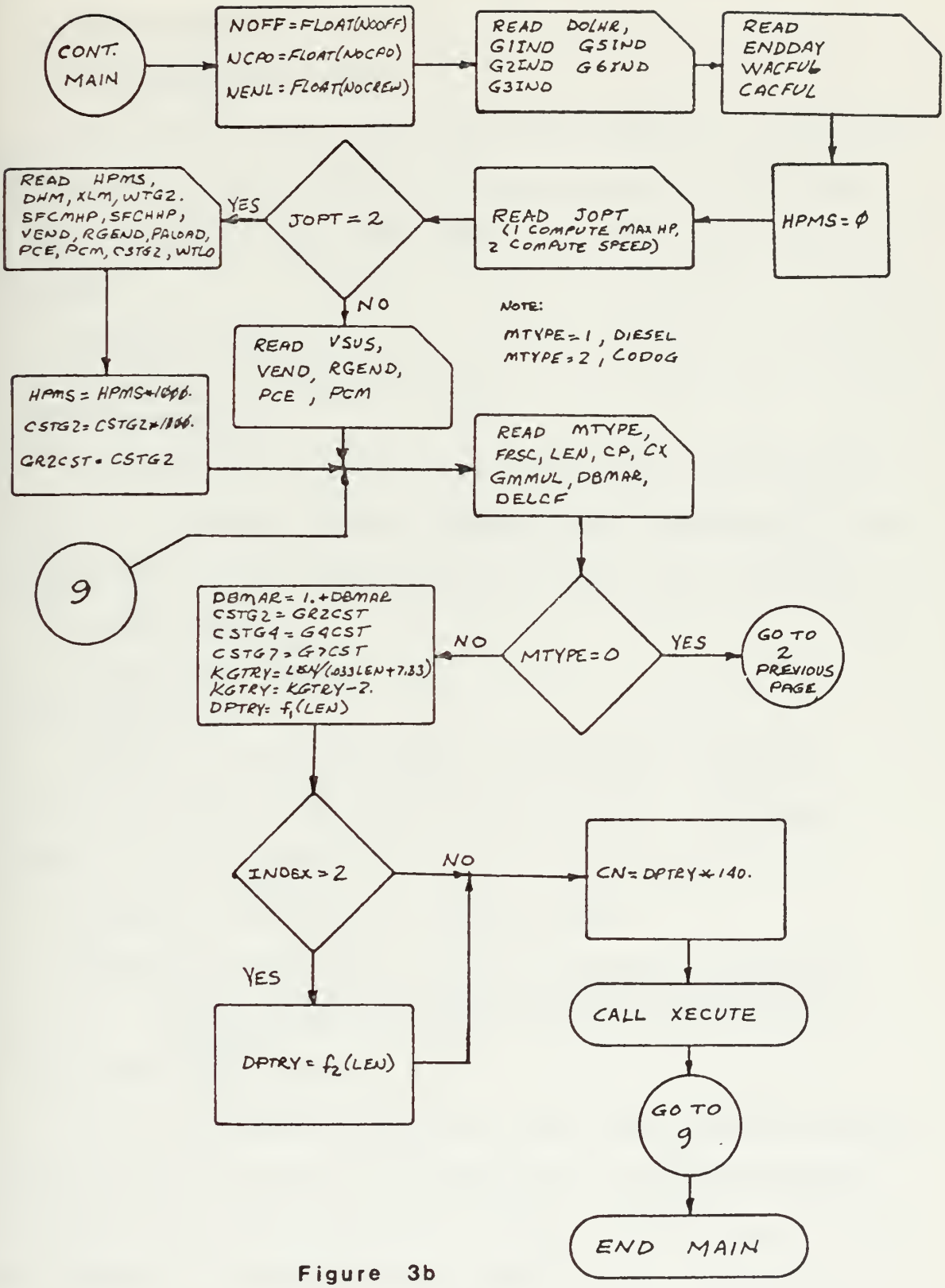

CONT. MAIN
NOFF = FLOAT(NOOFF)
NCPO = FLOAT(NOCPO)
NENL = FLOAT(NOCREW)
READ DOLHR, G1IND G5IND G2IND G6IND G3IND
READ ENDDAY WACFUL CACFUL
HPMS = ∅
READ JOPT (1 COMPUTE MAX HP, 2 COMPUTE SPEED)
JOPT = 2
YES
READ HPMS, DHM, XLM, WTG2. SFCMHP, SFCHHP, VEND, RGEND, PALOAD, PCE, PCM, CSTG2, WTLO
NO
READ VSUS, VEND, RGEND, PCE, PCM
NOTE:
MTYPE = 1, DIESEL
MTYPE = 2, CODOG
HPMS = HPMS*1000.
CSTG2 = CSTG2*1000.
GR2CST = CSTG2
READ MTYPE, FRSC, LEN, CP, CX GMMUL, DBMAR, DELCF
9
DBMAR = 1. + DBMAR
CSTG2 = GR2CST
CSTG4 = G4CST
CSTG7 = G7CST
KGTRY = LEN/(.033LEN + 7.33)
KGTRY = KGTRY - 2.
DPTRY = f1(LEN)
MTYPE = 0
NO
YES
GO TO 2 PREVIOUS PAGE
INDEX > 2
NO
YES
DPTRY = f2(LEN)
CN = DPTRY * 140.
CALL XECUTE
GO TO 9
END MAIN

Figure 3b

It is also used to discern between full hull ships and fine hull ships for the initial guess of displacement.

Stop execution:

```
IF(INDEX.EQ.0) STOP
```

This is the only place where the program is directed to stop execution. However, if a data card is left out, the program will stop when there is no more data cards to read.

Heading input:

```
    READ(8,123)(HEAD(I),I=1,20)
123 FORMAT(20A4)
```

Variable HEAD contains any alphanumeric information. It will be printed without change at the beginning of the output for all test cases using the data which follows.

NOARM input:

```
    READ(8,100) NOARM
100 FORMAT(I2)
```

NOARM is the total number of armament, aircraft and cargo payload data cards which follow. A maximum value of 20 is allowed.

Armament, aircraft and cargo input:

```
    READ(8,101)((TITLE(J,I),J=1,5),CARGOW(I),CARGOC(I),
         GR/WT(I),GR/CG(I),AMOWT(I),AMOCG(I),ACWT(I),
         ACCG(I),ELLD(I),DHAR(I),HLAR(I),GR/CST(I),I=
         1,NOARM)
101 FORMAT(5A4,12F5.0)
```

Up to 20 armament, aircraft and cargo payload description cards are allowed. The data may be lumped together and appear on only one card or it may be broken up in any way desired. However, if a weight is given, a vertical

center of gravity must also be given on the same card immediately following the weight. The first 20 spaces on each card are reserved for an alphanumeric description of the payload items on the card. This is used as a line title in the output listing. Of the four weight categories on the card only the group 7 weights are included in the light ship weight. From a calculation standpoint it is unimportant whether ammunition or aircraft are listed separately or considered cargo. However, if they are listed as cargo they will be classified incorrectly in the output listing.

All vertical center of gravity values should be inputed as a multiplier of the hull depth at amidships. This number is easier to estimate than the actual center in feet. As an example, if a payload item has its center 10 feet above the baseline and the depth at amidships is 20 feet the value entered is 0.5.

The deckhouse area should include only the area that is required to be in the deckhouse. If the area could be in either the deckhouse or the hull it should be included in the hull area. The group 7 cost should include only the cost of materials and should be estimated for the time when the ship will be built. Because of format limitations the value input should be the true cost divided by 1000. All weights are in tons, all areas in square feet, all electrical loads in KW and all costs in dollars. This applies to all the input items.

Summing the payload data:

```
      WCARGO=0.
      WTG7=0.
      WTAMMO=0.
      WTAC=0.
      ELOAD=0.
      BLOAD=0.
      AREADH=0.
      AREAHL=0.
      CSTG7=0.
      DO 10 I=1,NOARM
      WCARGO=WCARGO+CARGOW(I)
      WTG7=WTG7+GR7WT(I)
      WTAMMO=WTAMMO+AMOWT(I)
      WTAC=WTAC+ACWT(I)
      BLOAD=BLOAD+ELLD(I)
      GR7CST(I)=GR7CST(I)*1000.
      CSTG7=CSTG7+GR7CST(I)
      AREADH=AREADH+DHAR(I)
   10 AREAHL=AREAHL+HLAR(I)
```

Only the totals of the payload items entered are needed for calculations. These totals are computed in the above statements.

NOELT input:

```
      READ(8,102) NOELT
  102 FORMAT(I2)
```

This variable serves the same purpose as NOARM. A maximum value of 20 is allowed.

Electronics input:

```
      READ(8,103)((TITLE(J,I+20),J=1,5),GR4WT(I),GR4CG(I),
           ELD(I),DHA(I),HLA(I),GR4CST(I),I=1,NOELT)
  103 FORMAT(5A4,6F5.0)
```

The comments made about armament input also apply here. Group 4 weights are included in the light ship weight. All items normally in group 4 should be included since no allowance is made in the program for navigation equipment.

Summing electronics input data:

```
      WTG4=0.
      CSTG4=0.
      DO 11 I=1,NOELT
      WTG4=WTG4+GR4WT(I)
      ELOAD=ELOAD+ELD(I)
      GR4CST(I)=GR4CST(I)*1000.
      CSTG4=CSTG4+GR4CST(I)
      AREADH=AREADH+DHA(I)
   11 AREAHL=AREAHL+HLA(I)
```

The comments about summing armament data also apply here. Note that the area in the hull and deckhouse is a combined total of all the payload inputs, both electronic and armament.

Storing initial costs:

```
      G4CST=CSTG4
      G7CST=CSTG7
```

Because the value of variables CSTG4 and CSTG7 are modified during the execution of the program, a record is required of their initial values so that they will be available if another test case using the same payload is run.

Manning input:

```
      READ(8,104) NOOFF,NOCPO,NOCREW
  104 FORMAT(3I5)
      NOFF=FLOAT(NOOFF)
      NCPO=FLOAT(NOCPO)
      NENL=FLOAT(NOCREW)
```

The number of officers, chief petty officers and crew members are input and then converted to real values so that they can be used in non-integer equations.

Cost indices input:

```
      READ(8,110)DOLHR,G1IND,G2IND,G3IND,G5IND,G6IND
  110 FORMAT(6F5.0)
```

The labor rate for the year the ship will be built must be estimated as must the inflation corrections for material costs. These corrections are for the period from 1959 to the year the ship is to be built. Section 3.14 gives some guidance as to the values to use. The indices can also include special material costs such as making the hull out of HY-80 steel instead of mild steel.

Military mission consumables input:

```
    READ(8,105)ENDDAY,WACFUL,CACFUL
105 FORMAT(3F5.0)
```

The number of endurance days for dry provisions should be given. All other endurance days are taken as a suitable fraction of this number. The weight and center of gravity of aircraft fuel must also be given.

```
    HPMS=0.
```

This is done so that there is no difficulty in calling subroutine XECUTE.

JOPT input:

```
    READ(8,106) JOPT
106 FORMAT(I2)
    IF(JOPT.EQ.2)GOTO 1
```

This variable denotes the option to be used in entering vehicle performance data. If JOPT equals 1, the maximum sustained speed is input. If JOPT equals 2, the maximum sustained horsepower and machinery characteristics are input.

Vehicle performance input for JOPT equal 1:

```
    READ(8,107)VSUS,VEND,RGEND,PCE,PCM
107 FORMAT(2F5.0,F10.0,2F5.0)
    GOTO 9
```

The maximum sustained speed is input along with the endurance speed and endurance range. The propulsive coefficients at the endurance speed and at maximum speed must also be given.

Vehicle performance input for JOPT equal 2:

```
  1 READ(8,108)HPMS,DHM,XLM,WTG2SFCMHP,SFCHHP,VEND,RGEND,
        PALOAD,PCE,PCM,CSTG2,WTLO
108 FORMAT(7F5.0,F10.0,5F5.0)
    HPMS=HPMS*1000.
    CSTG2=CSTG2*1000.
    GR2CST=CSTG2
```

This option is used primarily when a specific machinery plant is desired. Besides the maximum sustained horsepower, the length and minimum depth of the engine room must be given. The total group 2 weight and specific fuel consumptions at maximum and half power are required. The endurance speed and range must be given as before. Propulsion auxiliaries electrical load and propulsive coefficients at full and endurance speed are required as are the group 2 material cost and lub oil weight.

To fit into the format used, the horsepower and cost values must be divided by 1000. The cost of group 2 must be stored for later use as were the costs of group 4 and group 7.

Options input:

```
  9 READ(8,109)MTYPE,FRSC,LEN,CP,CX,GMMUL,DBMAR,DELCF
109 FORMAT(I5,6F5.0,F10.0)
```

Machinery type must always be specified even if the option of inputing machinery characteristics was used. If machinery information was given, any number except

zero can be used for MTYPE. A value of zero will cause the program to assume the next input value is INDEX. This can be used to return and stop the program or to input a new set of data for another ship. If the machinery particulars have not been specified, MTYPE equals zero has the same effect. However, MTYPE equals 1 will cause the program to assume a diesel plant is to be installed. A value of MTYPE equal to 2 will result in calculations for a CODOG plant. These are the only two machinery types for which estimating relationships have been included in the program. If MTYPE is any other number, the results are unpredictable.

A free surface correction can be specified. This value is interpreted as a rise in the full load KG of the ship in an amount equal to FRSC in feet. A negative value can also be used. In this case FRSC can be interpreted as a lowering of the average KG value built into the program.

The length between perpendiculars is given next. The values for $C_p$ and $C_x$ have the standard naval architectural definitions.[3] GMMUL if the fraction GM/Beam, A value of 0.1 is commonly used. The next variable, DBMAR, is a design and builders margin. This is given as a fraction, i.e., a 10 percent margin is input as 0.1. DELCF is the $\Delta C_f$ value used in the calculation of horsepower. A value of 0.0004 is common.

```
IF(MTYPE.EQ.0) GOTO 2
```

One or more option input cards may follow the first. The program will assume that each one is a new input case with all other data the same. To input an entirely new set of data, an option input card with a value of MTYPE equal to zero should be included. No other values need be given on the card. This will cause the next input card to be interpreted as a new value for INDEX.

```
DBMAR=1.+DBMAR
CSTG2=GR2CST
CSTG4=G4CST
CSTG7=G7CST
```

DBMAR is changed to a multiplier for weight and the input costs are reset to their initial values.

Initial KG estimate:

```
KGTRY=LEN/(.0465*LEN+4.825)
KGTRY=KGTRY-2.
```

The initial KG value is estimated based on the values for current Coast Guard vessels. These are shown in Figure 4. Reducing the initial estimate by 2 feet was found to be advantageous. It helps to insure that the first iteration will not exceed the KG constraints of the program.

Initial displacement estimate:

```
DPTRY=(.006562-.001188*LEN/100.)*LEN**3/35.
IF(INDEX.EQ.2)DPTRY=.0025*LEN**3/35.
```

Two initial values of displacement are available. For an INDEX value other than 2 the displacement is taken as that of conventional Coast Guard vessels. This displacement curve is shown on Figure 4. However, if the

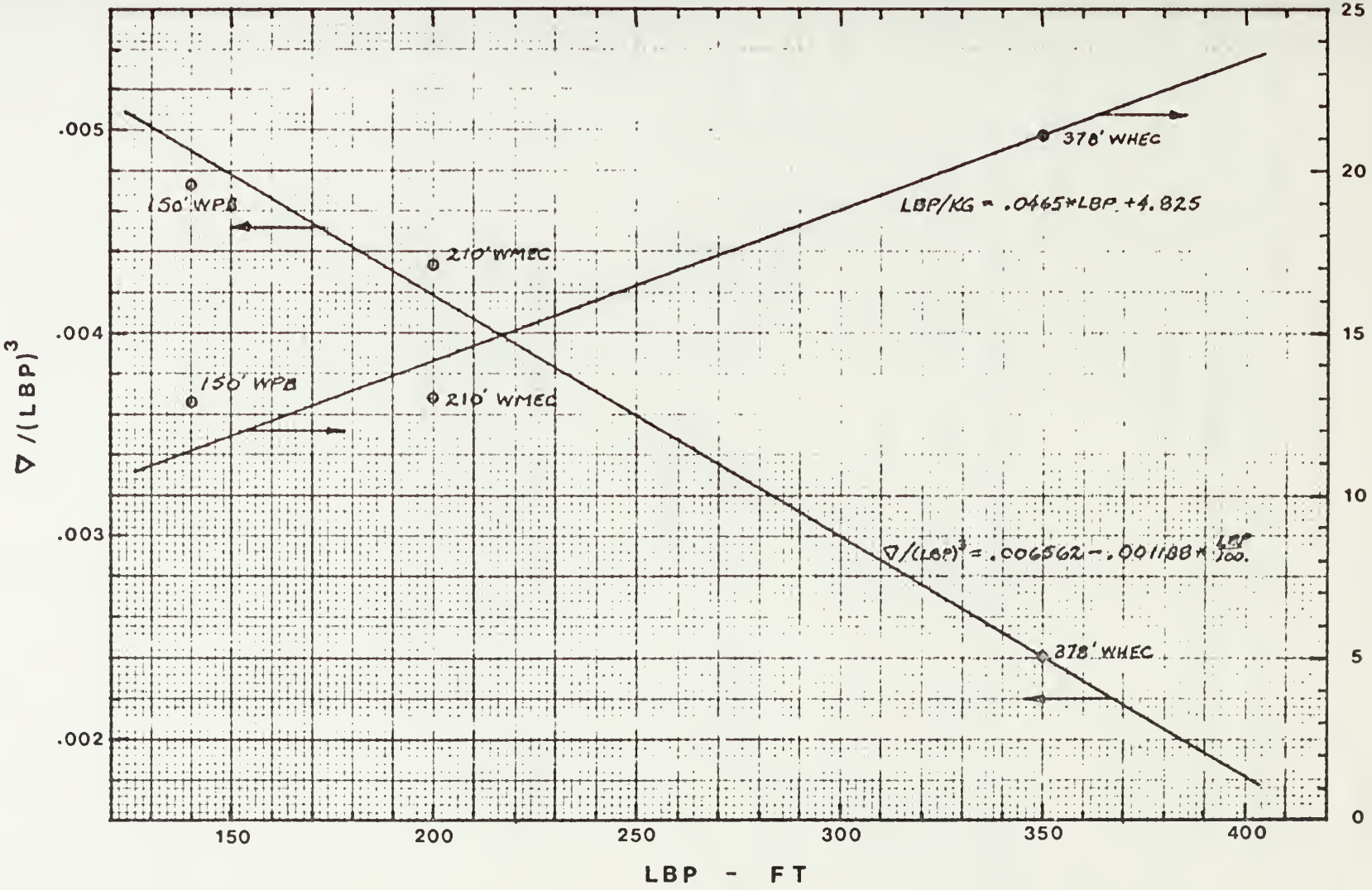

.005
.004
.003
.002
∇/(LBP)³
150' WPB
210' WMEC
378' WHEC
LBP/KG = .0465*LBP +4.825
150' WPB
210' WMEC
∇/(LBP)³ = .006562 − .001188 × LBP/100.
378' WHEC
150
200
250
300
350
400
LBP - FT
25
20
15
10
5
0
LBP / KG f.l.

Figure 4

vessel has a high speed-length ratio, greater than 1.3, it will not be possible to find the horsepower in some cases if the conventional ship curve is used. This is due to the limitations on the $C_r$ arrays. By specifying an INDEX equal to 2 the program assumes a fine form at least for the first iteration.

Cubic number estimate:

```
CN=DPTRY*160
```

An initial cubic number is assumed for use in estmating the electrical load on the first iteration. Values for current Coast Guard vessels range from 140 to 180 times the displacement.

```
CALL XECUTE(HPMS)
```

Control is transferred to subroutine XECUTE to calculate the vessels characteristics.

```
GOTO 9
END
```

The GOTO statement causes the program to loop back and try to read another options input data card. The END statement stops compilation of the routine.

3.2.4 List of Outputs of MAIN Subroutine

ACCG(20).....LC(EE)
ACWT(20).....LC(EE)
AMCCG(20).....LC(EE)
AMCWT(20).....LC(EE)
AREADH.....LC(BB)
AREAHL.....LC(BB)
BLOAD.....LC(DD)
CACFUL.....LC(HH)
CARGOC(20).....LC(EE)
CARGOW(20).....LC(EE)
CN.....LC(BB)
CP.....LC(GG)
CR1(1152).....LC(TT)
CR2(972).....LC(TT)
CR3(216).....LC(TT)
CSTG2**.....LC(MM)
CSTG4.....LC(MM)
CSTG7.....LC(MM)
CX.....LC(GG)
DBMAR.....LC(WW)
DELCF.....LC(CC)
DHA(20).....LC(KK)
DHAR(20).....LC(KK)
DHM**.....LC(JJ)
DOLHR.....LC(NN)
DPTRY.....LC(GG)
ELD(20).....LC(KK)
ELLD(20).....LC(KK)
ELOAD.....LC(DD)
ENDDAY.....LC(AA)
FRSC.....LC(GG)
G1IND.....LC(NN)
G2IND.....LC(NN)
G3IND.....LC(NN)
G5IND.....LC(NN)
G6IND.....LC(NN)
GMMUL.....LC(GG)
GR4CG(20).....LC(EE)
GR4CST(20).....LC(KK)
GR4WT(20).....LC(EE)
GR7CG(20).....LC(EE)
GR7CST(20).....LC(KK)
GR7WT(20).....LC(EE)
HEAD(20).....LC(FF)
HLA(20).....LC(KK)
HLAR(20).....LC(KK)
HPMS.....SCDA
JOPT.....LC(CC)
KGTRY.....LC(GG)
LEN.....LC(BB)
MTYPE.....LC(CC)
NCPO.....LC(AA)

List of Outputs of MAIN Subroutine (cont)

NENL.....LC(AA)
NOARM.....LC(FF)
NOELT.....LC(FF)
NOFF.....LC(AA)
PALOAD**.....LC(DD)
PCE.....LC(CC)
PCM.....LC(CC)
RGEND.....LC(CC)
SFCHHP**.....LC(CC)
SFCMHP**.....LC(CC)
TITLE(5,40).....LC(FF)
VEND.....LC(CC)
VSUS*.....LC(CC)
WACFUL.....LC(LL)
WCARGO.....LC(LL)
WTAC.....LC(LL)
WTAMMO.....LC(LL)
WTG2**.....LC(WW)
WTG4.....LC(WW)
WTG7.....LC(WW)
WTLO**.....LC(LL)
XLM**.....LC(JJ)

* Output only if JOPT = 1

** Output only if JOPT = 2

3.2.5 Nomenclature List

| | |
|---|---|
| ACCG(20) | aircraft vcg/D10, D10 = depth amidships |
| ACWT(20) | aircraft weight, tons |
| AMOCG(20) | ammunition vcg/D10 |
| AMOWT(20) | ammunition weight, tons |
| AREADH | total input deckhouse arrangements area, sq ft |
| AREAHL | total input hull arrangements area, sq ft |
| AVGKW | average electrical load, KW |
| B | maximum beam, feet |
| BLOAD | total armament electrical load, KW |
| CACFUL | aircraft fuel vcg/D10 |
| CARGOC(20) | cargo vcg/D10 |
| CARGOW(20) | cargo weight, tons |
| CCARGO | total vcg of cargo inputs, feet |
| CCST | construction services cost, dollars |
| CGAC | total vcg of aircraft, feet |
| CGAMMO | total vcg of ammunition, feet |
| CGCREW | total vcg of crew, feet |
| CGFUEL | total vcg of ships fuel, feet |
| CGLO | total vcg of lub oil, feet |
| CGPE | total vcg of personal effects, feet |
| CGPS | total vcg of personnel stores, feet |
| CN | cubic number, cubic ft |
| CP | prismatic coefficient |
| CR1(1152), CR2(972), CR3(216) | $C_r$ arrays for Taylor's Standard Series resistance estimate |

Nomenclature List (cont)

| | |
|---|---|
| CSTG1 | total cost of weight group 1, dollars |
| CSTG2 | total cost of weight group 2, dollars |
| CSTG3 | total cost of weight group 3, dollars |
| CSTG4 | total cost of weight group 4, dollars |
| CSTG5 | total cost of weight group 5, dollars |
| CSTG6 | total cost of weight group 6, dollars |
| CSTG7 | total cost of weight group 7, dollars |
| CWP | waterplane coefficient |
| CX | midship section coefficient |
| DAVG | average hull depth, feet |
| DBMAR | design and builders margin |
| DCST | design cost, dollars |
| DELCF | $\Delta C_f$ used in resistance calculation |
| DHA(20) | electronics deckhouse area, sq ft |
| DHAR(20) | armament deckhouse area, sq ft |
| DHM | minimum machinery box depth, feet |
| DHV | deckhouse volume, cu ft |
| DOLHR | labor rate, dollars/hour |
| DPTRY | displacement estimate, tons |
| ELD(20) | electronics electrical load, KW |
| ELKW | generator rated load, KW |
| ELLD(20) | armament electrical load, KW |
| ELOAD | total electronics electrical load, KW |
| ENCVOL | total volume of hull and deckhouse, cu ft |
| ENDDAY | number of endurance days for dry provisions |
| FRSC | free surface correction, feet |

Nomenclature List (cont)

| | |
|---|---|
| G1IND | cost index for weight group 1 |
| G2IND | cost index for weight group 2 |
| G3IND | cost index for weight group 3 |
| G4CST | total material cost weight group 4, dollars |
| G5IND | cost index for weight group 5 |
| G6IND | cost index for weight group 6 |
| G7CST | total material cost weight group 7, dollars |
| GMMUL | GM/Beam ratio |
| GR2CST | total material cost weight group 2, dollars |
| GR4CG(20) | group 4 vcg/D10 |
| GR4CST(20) | material cost weight group 4, dollars |
| GR4WT(20) | group 4 weight, tons |
| GR7CG(20) | group 7 vcg/D10 |
| GR7CST(20) | material cost weight group 7, dollars |
| GR7WT(20) | group 7 weight, tons |
| H | draft, feet |
| HEAD(20) | descriptive heading (alphanumeric) |
| HLA(20) | electronics hull area, sq ft |
| HLAR(20) | armament hull area, sq ft |
| HPMS | maximum sustained shaft horsepower |
| INDEX | control variable |
| JOPT | input option variable for machinery |
| KGTRY | initial KG estimate, feet |
| LEN | length between perpendiculars, feet |
| LRD | raised deck length, feet |
| MCST | miscellaneous costs, dollars |

Nomenclature List (cont)

| | |
|---|---|
| MTYPE | machinery type option |
| NCPO | number of chief petty officers (real) |
| NENL | number of enlisted men (real) |
| NOARM | number of armament input cards |
| NOELT | number of electronics input cards |
| NOFF | number of officers (real) |
| NOCPO | number of chief petty officers (integer) |
| NOCREW | number of enlisted men (integer) |
| NOOFF | number of officers (integer) |
| PALOAD | propulsion auxiliary electrical load, KW |
| PCE | propulsive coefficient at endurance speed |
| PCM | propulsive coefficient at maximum speed |
| RGEND | endurance range, nautical miles |
| SFCHHP | specific fuel consumption at half horsepower, lbs/SHP-hr |
| SFCMHP | specific fuel consumption at maximum horsepower, lbs/SHP-hr |
| SHPE | shaft horsepower at endurance speed |
| SHPM | shaft horsepower at maximum speed |
| TITLE(5,40) | line titles.(alphanumeric) |
| TOTCST | total lead ship cost, dollars |
| VEND | endurance speed, knots |
| VSUS | maximum sustained speed, knots |
| WACFUL | weight of aircraft fuel, tons |
| WCARGO | total cargo weight, tons |
| WFULLD | full load weight, tons |

Nomenclature List (cont)

| | |
|---|---|
| WLSHIP | light ship weight, tons |
| WTAC | total aircraft weight, tons |
| WTAMMO | total ammunition weight, tons |
| WTCREW | total crew weight, tons |
| WTFUEL | total ships fuel weight, tons |
| WTG1 | total group 1 weight, tons |
| WTG2 | total group 2 weight, tons |
| WTG3 | total group 3 weight, tons |
| WTG4 | total group 4 weight, tons |
| WTG5 | total group 5 weight, tons |
| WTG6 | total group 6 weight, tons |
| WTG7 | total group 7 weight, tons |
| WTLO | weight of lub oil, tons |
| WTPE | weight of personal effects, tons |
| WTPS | weight of personnel stores, tons |
| XLM | machinery box length, feet |

## 3.3 Subroutine XECUTE

### 3.3.1 Introduction

Subroutine XECUTE controls the execution of each trial case. All of the remaining subroutines except two are called by this routine. Error messages are also printed by this routine whenever a constraint of the program is violated.

In three cases, iteration control statements have been included in XECUTE. The first set of these statements controls the convergence of the speed-power estimate when maximum sustained horsepower is specified. A modified Newton-Raphson technique[2] is used with the slope approximated by a secant to the speed-power curve.

The second set of iteration control statements controls the convergence between estimated displacement and full load weight. A similar modified Newton-Raphson technique is used.

The last set deals with the convergence of the vertical center of gravity estimate. For this set there is a tendency for the values to oscillate and a Newton-Raphson technique could not be used. The average of the estimated and calculated values of KG is used instead. While this eliminates the oscillations, convergence may be slow in some cases.

A flow chart for this subroutine is shown in Figures 5a, 5b, 5c, and 5d.

# XECUTE SUBROUTINE FLOW CHART

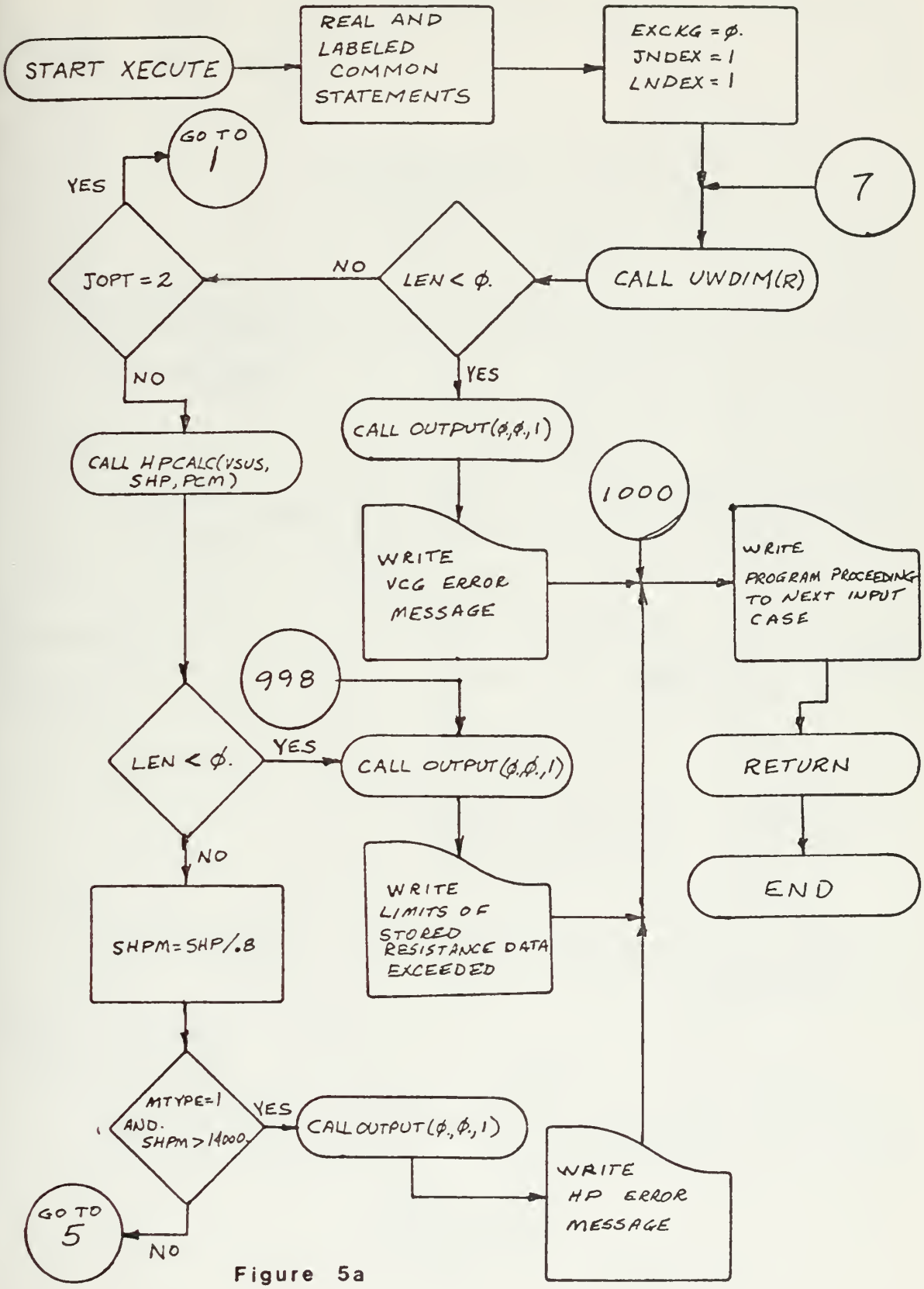



Figure 5a

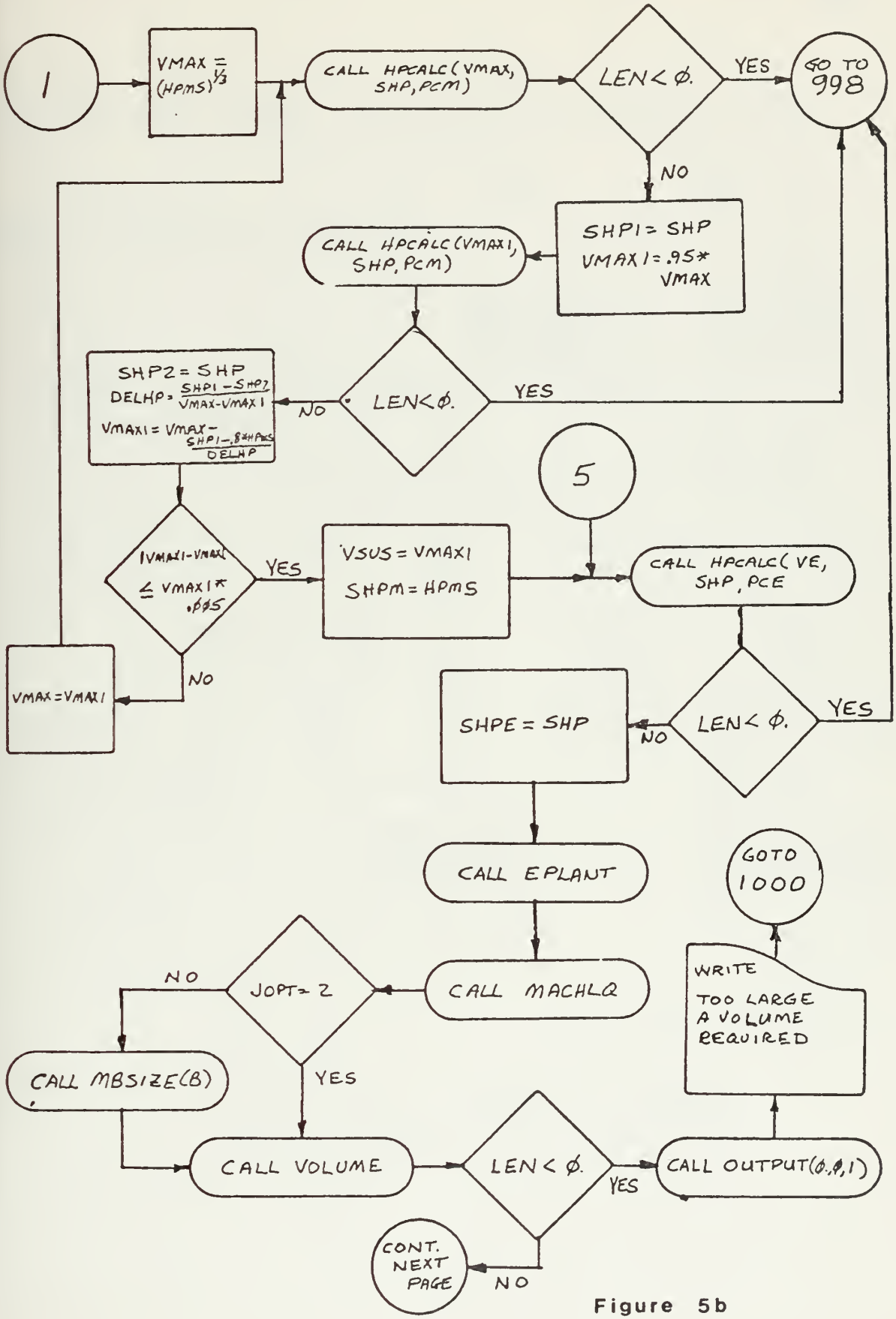

1
VMAX = (HPMS)^1/3
CALL HPCALC(VMAX, SHP, PCM)
LEN < ϕ.
YES
GO TO 998
NO
SHP1 = SHP
VMAX1 = .95* VMAX
CALL HPCALC(VMAX1, SHP, PCM)
LEN < ϕ.
YES
NO
SHP2 = SHP
DELHP = (SHP1 - SHP2) / (VMAX - VMAX1)
VMAX1 = VMAX - (SHP1 - .8*HPMS) / DELHP
5
|VMAX1 - VMAX| ≤ VMAX1 * .005
YES
VSUS = VMAX1
SHPM = HPMS
CALL HPCALC(VE, SHP, PCE
NO
VMAX = VMAX1
SHPE = SHP
LEN < ϕ.
NO
YES
CALL EPLANT
GOTO 1000
WRITE TOO LARGE A VOLUME REQUIRED
NO
JOPT = 2
CALL MACHLQ
CALL MBSIZE(B)
YES
CALL VOLUME
LEN < ϕ.
YES
CALL OUTPUT(ϕ.ϕ,1)
CONT. NEXT PAGE
NO

Figure 5b

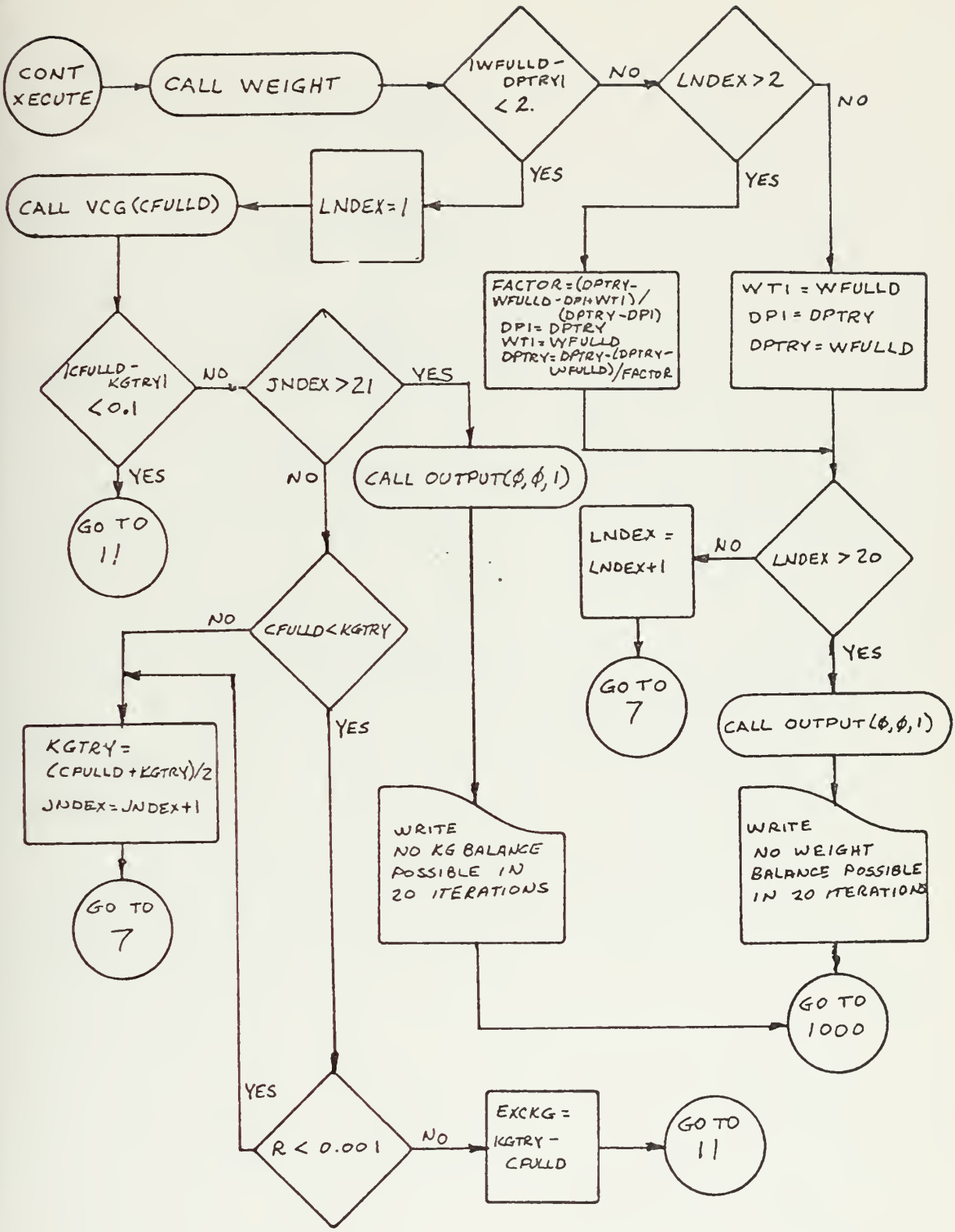

CONT
XECUTE
CALL WEIGHT
|WFULLD - DPTRY| < 2.
NO
LNDEX > 2
NO
YES
YES
LNDEX = 1
CALL VCG (CFULLD)
FACTOR = (DPTRY - WFULLD - DPI + WT1) / (DPTRY - DPI)
DPI = DPTRY
WT1 = WFULLD
DPTRY = DPTRY - (DPTRY - WFULLD) / FACTOR
WT1 = WFULLD
DPI = DPTRY
DPTRY = WFULLD
|CFULLD - KGTRY| < 0.1
NO
JNDEX > 21
YES
YES
NO
CALL OUTPUT(ϕ, ϕ, 1)
GO TO 11
LNDEX = LNDEX + 1
NO
LNDEX > 20
GO TO 7
YES
NO
CFULLD < KGTRY
YES
CALL OUTPUT(ϕ, ϕ, 1)
KGTRY = (CFULLD + KGTRY) / 2
JNDEX = JNDEX + 1
WRITE NO KG BALANCE POSSIBLE IN 20 ITERATIONS
WRITE NO WEIGHT BALANCE POSSIBLE IN 20 ITERATIONS
GO TO 7
GO TO 1000
YES
R < 0.001
NO
EXCKG = KGTRY - CFULLD
GO TO 11

Figure 5c

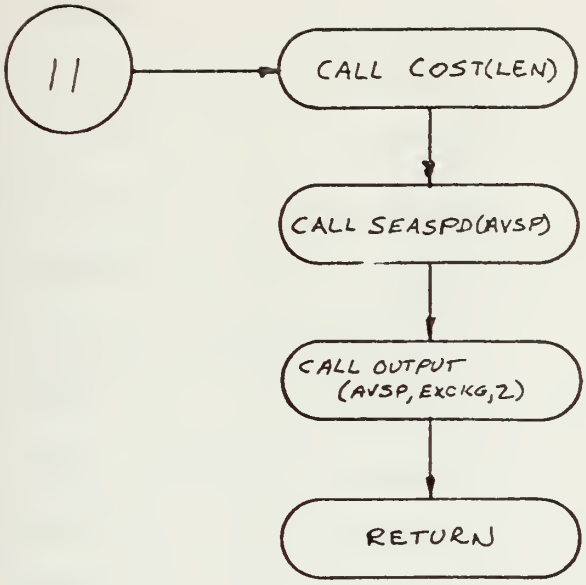

11
CALL COST(LEN)
CALL SEASPD(AVSP)
CALL OUTPUT
(AVSP, EXCKG, 2)
RETURN

Figure 5d

3.3.2 Input List for Subroutine XECUTE

DPTRY.....LC(GG)

HPMS.....SCDA  Only if JOPT = 2

JOPT.....LC(CC)

KGTRY.....LC(GG)

LEN.....LC(BB)

MTYPE.....LC(CC)

PCE.....LC(CC)

PCM.....LC(CC)

VE.....LC(CC)

VSUS.....LC(CC)  Only if JOPT = 1

WFULLD.....LC(WW)

3.3.3 Statement Descriptions

REAL and COMMON statements will not be listed with individual subroutines but may be found in Appendix C.

```
EXCKG=0.
JNDEX=1
LNDEX=1
```

These statements initialize values for the excess KG variable, the VCG loop counter and the weight loop counter respectively.

```
7 CALL UWDIM(R)
```

This subroutine is called to calculate the beam and draft of the ship. The variable R transfers the value of any excess KG.

```
IF(LEN.LT.0.) GOTO 999
```

If a beam to draft ratio of greater than 4.0 is

required to satisfy the stability requirements, LEN is set equal to -1000. in UWDIM. This signals XECUTE to print an error message and return control to MAIN.

```
IF(JOPT.EQ.2) GOTO 1
```

The next group of statements control the speed-power estimate. Two procedures are used depending on which performance input option is specified.

```
CALL HPCALC(VSUS,SHP,PCM)
IF(LEN.LT.0.) GOTO 998
GOTO 2
```

These statements are used if the sustained speed is specified. Subroutine HPCALC is designed to return a value of shaft horsepower, SHP, if speed and propulsive coefficient are specified. In this case VSUS is the speed and PCM the propulsive coefficient used.

LEN is used here also as a signal that an error message is required. A negative length, LEN, will occur if the limits of the $C_r$ array are exceeded. The ranges of the $C_r$ array are:

$$.48 \leq C_p \leq .70$$

$$2. \leq B/T \leq 4.$$

for $.001 \leq C_v \leq .003$

$$.5 \leq V/\sqrt{L} \leq 2.$$

for $.003 \leq C_v \leq .006$

$$.5 \leq V/\sqrt{L} \leq 1.3$$

The GOTO 2 statement causes the routine to skip the speed estimate used when JOPT = 2.

```
1 VMAX = (HPMS*200./LEN)**.33333
```

If the maximum sustained horsepower, HPMS, was specified, the following statements are used for estimating the maximum sustained speed. The statement given above provides a rough first guess at the speed.

```
4 CALL HPCALC(VMAX,SHP,PCM)
  IF(LEN.LT.0.) GOTO 998
  SHP1=SHP
  VMAX1=.95*VMAX
  CALL HPCALC(VMAX1,SHP,PCM)
  IF(LEN.LT.0) GOTO 998
  SHP2=SHP
```

Two points on the speed-power curve are calculated in the above statements, one point at VMAX and one point at .95 x VMAX. The constant, .95, was chosen arbitrarily to give a secant to the curve which has a slope close to the actual slope at VMAX. The same limits of the $C_r$ array apply here.

```
DELHP=(SHP1-SHP2)/(VMAX-VMAX1)
```

This is the approximate value of

$$\frac{d(SHP)}{dV} \quad \text{at VMAX}$$

```
VMAX1=VMAX-(SHP1-.8*HPMS)/DELHP
```

By definition the maximum sustained speed is the speed that can be made when the shaft horsepower is 80 percent of the maximum sustained horsepower. This assumes the ship has a clean bottom and is operating in calm water. Therefore, the function to be solved is:

$$f(V) = SHP(V) - .8 \times HPMS = 0$$

The Newton-Raphson method is an iterative procedure

in which:

$$V_{k+1} = V_k - \frac{f(V_k)}{f'(V_k)}$$

$$\text{where } f'(V_k) = \frac{d\, f(V)}{d\, V}\Big|_{V_k}$$

In the present case:

$V_k$ = VMAX

$V_{k+1}$ = VMAX1

$f(V_k)$ = SHP1 - .8 x HPMS

$f'(V_k)$ = DELHP

DELHP is only an approximation to $f'(V_k)$; however, it produces very good convergence.

```
IF(ABS(VMAX1-VMAX).LE.VMAX1*.005) GOTO 3
```

The iteration stops when the difference between any two successive speed estimates is less than half a percent of the best estimate. The above iteration technique is very fast and convergence to these limits usually occurs in 3 to 4 iterations.

```
VMAX = VMAX1
GOTO 4
```

These statements are used if the two speed estimates are not within the above limit. The new velocity estimate is used and another iteration is run.

```
  3 VSUS = VMAX1
    SHPM = HPMS
    GOTO 5
```

The above pair of values are saved for output and for use in other subroutines.

```
  2 SHPM = SHP/.8
```

In the case where VSUS is specified, the value SHP

is equal to SHPM times .8 as before.

```
IF(MTYPE.EQ.1.AND.SHPM.GT.14000.) GOTO 997
```

If a diesel plant is specified, horsepowers of greater than 14000 are outside the range of validity of the model. An error message is printed if this occurs.

```
5 CALL HPCALC(VE,SHP,PCE)
  IF(LEN.LT.0.) GOTO 998
  SHPE=SHP
```

The endurance horsepower is calculated without regard to fouling or sea conditions. This statement is executed for both performance options.

```
CALL EPLANT
```

This subroutine is called to calculate the average electrical load at sea and to size the ships generators.

```
CALL MACHLQ
```

This subroutine is called to calculate the weight of fuel, lub oil and potable water required.

```
IF(JOPT.EQ.2) GOTO 6
CALL MBSIZE(B)
```

Subroutine MBSIZE calculates the length and minimum depth of the machinery box. If JOPT = 2 these values are given as input.

```
6 CALL VOLUME
  IF(LEN.LT.0) GOTO 996
```

Subroutine VOLUME sets the sheer line and balances the required area and available area. If insufficient area is available, the value of LEN will be negative.

```
CALL WEIGHT
```

All the weights not previously estimated or inputed

are calculated in this routine. The primary value returned is WFULLD, the full load weight.

```
IF(ABS(WFULLD-DPTRY).LT.2.) GOTO 8
```

The calculated full load weight is compared to the displacement estimate made earlier. If the two do not agree within 2 tons, a new estimate of displacement is made and the program returns to call UWDIM. If there is agreement, the program proceeds to calculate vertical center of gravity.

```
IF(LNDEX.GE.2) GOTO 9
WT1=WFULLD
DP1=DPTRY
DPTRY=WFULLD
GOTO 10
```

Two values of weight and two values of displacement are needed for the Newton-Raphson procedure explained below to work. On the first iteration, the above simplified procedure is used.

```
  9 FACTOR=(DPTRY-WFULLD-DP1+WT1)/(DPTRY-DP1)
    DP1=DPTRY
    WT1=WFULLD
    DPTRY=DPTRY-(DPTRY-WFULLD)/FACTOR
```

In this case:

$$f(DPTRY) = DPTRY - WFULLD(DPTRY) = 0$$

Again a secant approximation is made to f'(DPTRY). This is the variable FACTOR.

$$DPTRY_{k+1} = DPTRY_k - \frac{f(DPTRY)}{f'(DPTRY)}$$

```
 10 IF(LNDEX.GT.20) GOTO 995
```

In case the iteration does not converge, this statement

provides a safety valve to stop the loop. An error message is printed.

```
      LNDEX=LNDEX+1
      GOTO 7
```

A new iteration is run beginning with a call to UWDIM.

```
    8 CONTINUE
      LNDEX=1
      CALL VCG(CFULLD)
```

Once the full load weight is sufficiently close to displacement, the program proceeds to calculate KG. The weight counter is reset. The value CFULLD is the calculated KG. This value is compared with the previous estimate, KGTRY.

```
      IF(ABS(CFULLD-KGTRY).LT..1) GOTO 11
```

This iteration stops when the two KG values are less than 0.1 feet apart.

```
      IF(JNDEX.GT.21) GOTO 994
```

Again a safety valve is provided in case the iteration does not converge.

```
      IF(CFULLD.LT.KGTRY) GOTO 12
   13 KGTRY=(CFULLD+KGTRY)/2.
      JNDEX=JNDEX+1
      GOTO 7
   12 IF(R.LT..001) GOTO 13
      EXCKG=KGTRY-CFULLD
```

In some cases the minimum beam to draft ratio may provide more stability than is required to satisfy the GM criterion. The ship is still feasible if this occurs, but may be over designed. When this occurs R will have a value greater than 0. In fact, it will be equal to the excess KG when KGTRY is used in UWDIM. The input value

of KGTRY is modified in UWDIM by adding R. Therefore, the value of KGTRY at this point in the program is the maximum value of vertical center of gravity for which a minimum beam to draft ratio will still be valid. If CFULLD is less than this value there is no point in doing another iteration. Instead, the program continues and eventually prints the excess KG available as an output.

In all other cases a new estimate of KGTRY must be made. As mentioned earlier, this estimate is taken as the average of the initial estimate and final calculated value. This is done to prevent the two values from oscillating. As an example, in the case of the 378' WHEC, a KGTRY of 14 feet returned a CFULLD of 16 feet. A KGTRY of 16 feet returned a CFULLD of 14 feet. This oscillation may not occur in other cases, but the averaging estimate used will converge in every case, although possibly at a slow rate.

```
 11 CONTINUE
    CALL COST(LEN)
```

Subroutine COST calculates any remaining cost items not given as input.

```
    CALL SEASPD(AVSP)
```

This subroutine estimates an average speed, AVSP, in the North Atlantic Ocean which includes the effects of sea state.

```
    CALL OUTPUT(AVSP,EXCKG,2)
```

Subroutine OUTPUT contains the write statements for printing all the output and input data. The value 2 causes OUTPUT to

print both the input and output data.

```
      RETURN
```

The present input case has been completed and control is returned to the MAIN program for more data.

The error message statements are all similar in format and generally self explanatory. Only one typical one will be discussed.

```
 994 CALL OUTPUT(0.,0.,1)
```

Subroutine OUTPUT is called with a value of 1. This directs OUTPUT to print only the input data.

```
      WRITE(5,106)
 106 FORMAT(///' NO BALANCE BETWEEN ASSUMED AND CALC KG
          WITHIN 0.1 FEET COULD BE MADE IN 20 ITERATIONS'///)
      GOTO 1000
1000 WRITE(5,102)
 102 FORMAT('PROGRAM PROCEEDING TO NEXT INPUT CASE'///)
      RETURN
      END
```

The program prints the appropriate error message and returns for more data. This concludes subroutine XECUTE.

### 3.3.4 Output List for Subroutine XECUTE

```
      DPTRY.....LC(GG)

      EXCKG.....SCDA

      KGTRY.....LC(GG)

      SHPE......LC(CC)

      SHPM......LC(CC)
```

### 3.3.5 Nomenclature List

All variables have the same definition as given in the MAIN program nomenclature list except for the following:

| | |
|---|---|
| AVSP | average speed in N.A. Ocean, knots |
| CFULLD | vertical center of gravity, KG, feet |
| DELHP | derivative of horsepower function |
| DP1 | used to store DPTRY value, tons |
| EXCKG | excess KG, feet |
| FACTOR | derivative of weight function |
| JNDEX | vcg counter |
| LNDEX | weight counter |
| R | excess KG, feet |
| RE | same as RGEND in MAIN |
| SFCH | same as SFCHHP in MAIN |
| SFCM | same as SFCMHP in MAIN |
| SHP | dummy used for shaft horsepower |
| SHP1 | dummy used for shaft horsepower |
| SHP2 | dummy used for shaft horsepower |
| VE | same as VEND in MAIN |
| VMAX | dummy used for speed, knots |
| VMAX1 | dummy used for speed, knots |
| WT1 | used to store WFULLD, tons |

## 3.4 Subroutine UWDIM

### 3.4.1 Introduction

Three of the important variables determining the underwater hull dimensions are given as input. These are length, $C_p$ and $C_x$. Two others, the beam and draft, are calculated in UWDIM. The waterplane coefficient, $C_{wp}$, is also calculated, but only as a linear function of $C_p$.

Displacement is an input to this subroutine and therefore the value of beam times draft is fixed since:

$$B \times T = \text{Displacement} \times 35./(L_{bp} \times C_p \times C_x) \quad \text{Ref.(3)}$$

Reference (3) may be referred to for a detailed definition of the naval architectural variables used in this routine.

The beam to draft ratio, B/T, is determined by the GM/B criterion. The GM available is given by the formula:

$$GM = KB + BM - KG - \text{Free surface correction} \quad \text{Ref.(3)}$$

Values for KG, free surface correction and GM/B are inputs to this routine. A value for KB is estimated using Morrish's approximate formula:[3]

$$KB = T - 1/3 \times (T/2 + V/A)$$

where T is the draft in feet

V is the volume of displacement =

$$B \times T \times L_{bp} \times C_p \times C_x \text{ , cu ft}$$

A is the waterplane area = $B \times L_{bp} \times C_{wp}$, sq ft

Substituting for V and A gives:

$$KB = T \times (5/6 - (C_p \times C_x)/(3 \times C_{wp}))$$

A value for BM is estimated using:

$$BM = \frac{Lbp \times B^3 \times C_\alpha}{\nabla}$$

where $C_\alpha$ is a transverse moment of inertia coefficient which is assumed to be a linear function of $C_{wp}$.

A number of coefficients are used in this routine which are defined by the above equations. These are listed below.

C1 = DPTRY*35./(LEN*CP*CX) = B x T

C2 = .833 - CP*CX/(3*CWP) = KB/T

C3 = LEN*CALPH/(DPTRY*35.) = $BM/B^3$

C4 = KG + FRSC

C5 = GM/B = GMMUL

Figure 7 gives a typical plot of the equation:

$$KB + BM - GM = C2 \times T + \frac{C3 \times C1^3}{T^3} - \frac{C1 \times C5}{T}$$

The curve shown was calculated using data for a 378' WHEC.

The value of KG is also plotted in Figure 7. In the discussion below, KG refers to the value of KG + FRSC. A variable R is now introduced with a value of:

$$R = KB + BM - GM - KG$$

When R = 0, the stability criterion that GM = C5 x B is just satisfied. This is the desired solution. This point is shown as point 3 in Figure 7.

However, the solution is only valid provided point 3 lies within satisfactory limits of beam to draft ratio. These limits are specified by the speed-power estimation

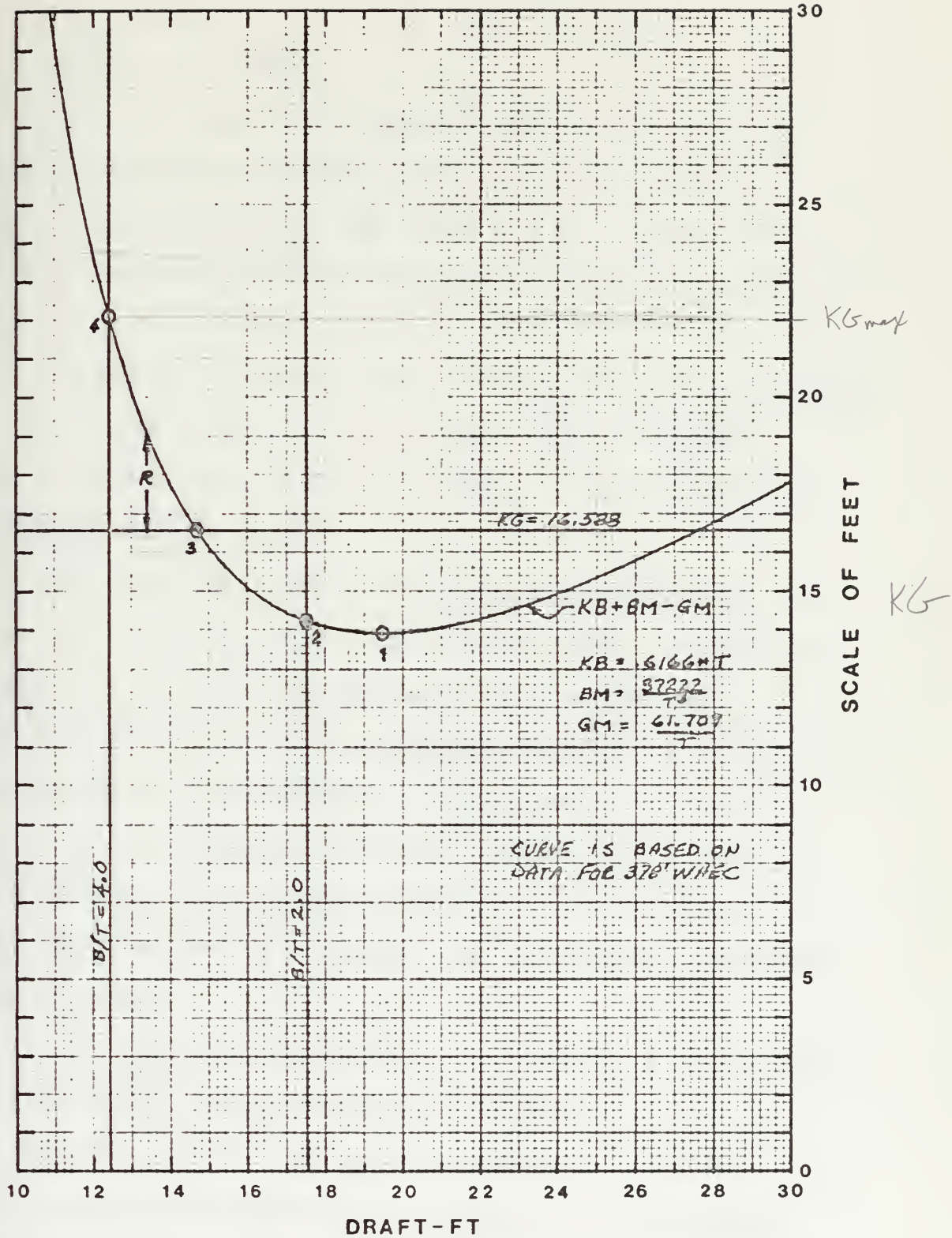

30
25
20
15
10
5
0
SCALE OF FEET
KGmax
KG
4
R
3
2
1
KG = 16.528
KB+BM-GM
KB = 6166MT
BM = 37222/T
GM = 41.70T
CURVE IS BASED ON DATA FOR 378' WHEC
B/T=4.0
B/T=2.0
10
12
14
16
18
20
22
24
26
28
30
DRAFT-FT

Figure 7

to be:

$$2. \leq B/T \leq 4.$$

or since B = C1/T

$$\sqrt{C1/4} \leq T \leq \sqrt{C1/2}$$

It can be seen from Figure 7 that if the value of KG is lower than the value of KB + BM - GM at point 1 there would be no draft for which R = 0. The minimum GM that could be provided would still be greater than C5 x B.

The solution method used in UWDIM proceeds as follows:

(1) The value of B/T at point 1 is calculated. Then a check is made to see if point 1 lies between the acceptable limits of B/T.

(2) If point 1 lies within the limits of B/T, the value of R is calculated. If R is positive, no solution exists to R = 0 but the ship may still be feasible. In this case the minimum GM is greater than C5 x B. When this occurs the KG estimate is raised until R = 0 at point 1 and the program returns to subroutine XECUTE. If it is found later that the actual KG of the ship is lower than the new KG estimate, the difference is printed as an excess KG.

If the value of R at point 1 is negative, the program executes the procedure described in step 4.

(3) If point 1 does not lie within acceptable limits of B/T, the value of R at point 2 is calculated. If R is positive at this point the procedure is the same

as that outlined in step 2. If R is negative, execution proceeds to step 4.

(4) If the value of KG is greater than the value of KB + BM - GM at point 1 or point 2, the value of R at point 4 is calculated. If the value of R is negative at this point, no draft can be specified within the limits of B/T that will satisfy the stability criterion and the program will have to go on to another input case.

If R is positive at point 4, the solution must lie between point 4 and point 1 or point 2, whichever is lower. It is assumed that if point 1 is within the limits on B/T that the solution does not lie between point 1 and point 2.

(5) To solve for the draft at which R = 0, a synthetic division technique is used together with the Newton-Raphson iteration technique. This is sometimes known as the Birge-Vieta method.[2] The equation for R must be modified slightly to use this technique.

$$f(T) = T^3R/C_2 = T^4 - C_4T^3/C_2 - C_1C_5T^2/C_2 + C_3C_1^3/C_2 = 0$$

In the Birge-Vieta method three columns are used as shown below:

| | | |
|---|---|---|
| 1 | 1 | 1 |
| $a_1$ | $b_1$ | $c_1$ |
| $a_2$ | $b_2$ | $c_2$ |
| $a_3$ | $b_3$ | $c_3$ |
| $a_4$ | $b_4$ | |

The values in the first column are the coefficients in the equation for f(T), namely:

$$a_1 = -C_4/C_2,\ a_2 = -C_1C_5/C_2,\ a_3 = 0,\ a_4 = C_3C_1^3/C_2$$

The values in columns two and three are calculated using the equations:

$$b_i = a_i + z \times b_{i-1}$$

$$c_i = b_i + z \times c_{i-1}$$

where z is the current estimate of the draft, T.

The new estimate of draft is then:

$$z_{new} = z - b_4/c_3$$

New values are computed for columns two and three using $z_{new}$. The procedure starts with the draft at point 4 and continues until the difference between $z_{new}$ and z is sufficiently small. This iteration procedure is very fast and usually only three or four iterations are required.

A flow chart for this subroutine is shown in Figures 6a and 6b.

3.4.2 Input List for Subroutine UWDIM

C4.....LC(GG)

C5.....LC(GG)

CP.....LC(GG)

CX.....LC(GG)

DISPL.....LC(GG)

FRSC.....LC(GG)

LEN.....LC(BB)

# UWDIM SUBROUTINE FLOW CHART

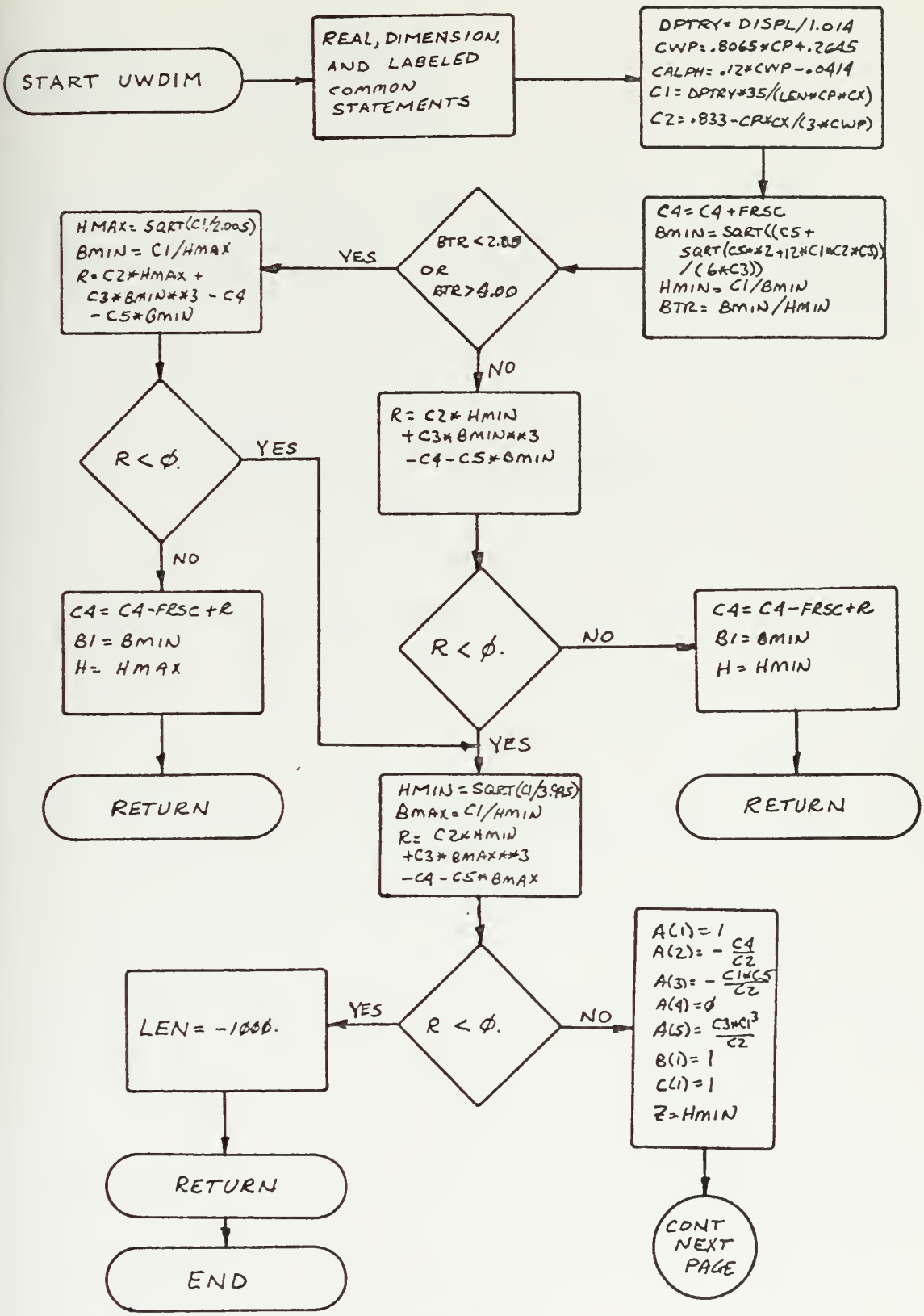



Figure 6a

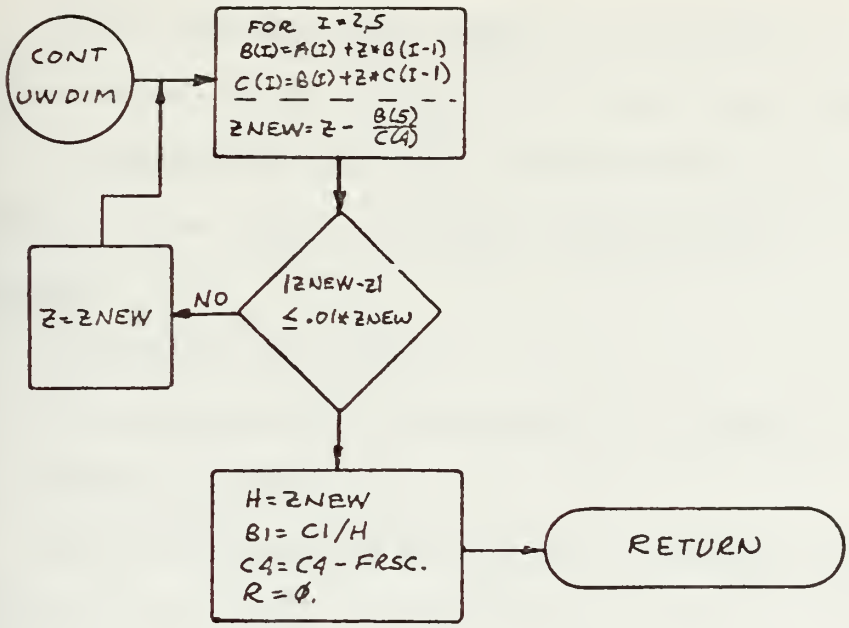

CONT
UW DIM
FOR I=2,5
B(I)=A(I)+Z*B(I-1)
C(I)=B(I)+Z*C(I-1)
ZNEW=Z-B(5)/C(4)
|ZNEW-Z|
≤.01*ZNEW
NO
Z=ZNEW
H=ZNEW
B1=C1/H
C4=C4-FRSC.
R=Ø.
RETURN

Figure 6b

3.4.3 Statement Descriptions

DPTRY = DISPL/1.014

DISPL has the value assigned to DPTRY in other subroutines. It is assumed that the total displacement is 1.4 percent greater than the molded displacement. DPTRY has the value of molded displacement in this subroutine.

CWP=.8065*CP+.2645

This relationship is plotted in Figure 8.

CALPH=.12*CWP-.0414

This relationship is plotted as Figure 8-8(b) in Reference (1). This relationship applies to destroyer ship types but was not checked against Coast Guard designs.

C1=DPTRY*35./(LEN*CP*CX)

C2=.833-CP*CX/(3.*CWP)

C3=LEN*CALPH/(DPTRY*35.)

C4=C4+FRSC

The derivation of these coefficients is described in the introduction to this section.

BMIN=SQRT((C5+SQRT(C5**2+12.*C1*C2*C3))/(6.*C3))

HMIN=C1/BMIN

BTR=BMIN/HMIN

IF(BTR.LT.2..OR.BTR.GT.4.) GOTO !

The ratio of B/T at point 1 in figure 7 is calculated using these statements. The formula for BMIN is derived by setting dR/dE = 0 and solving for B.

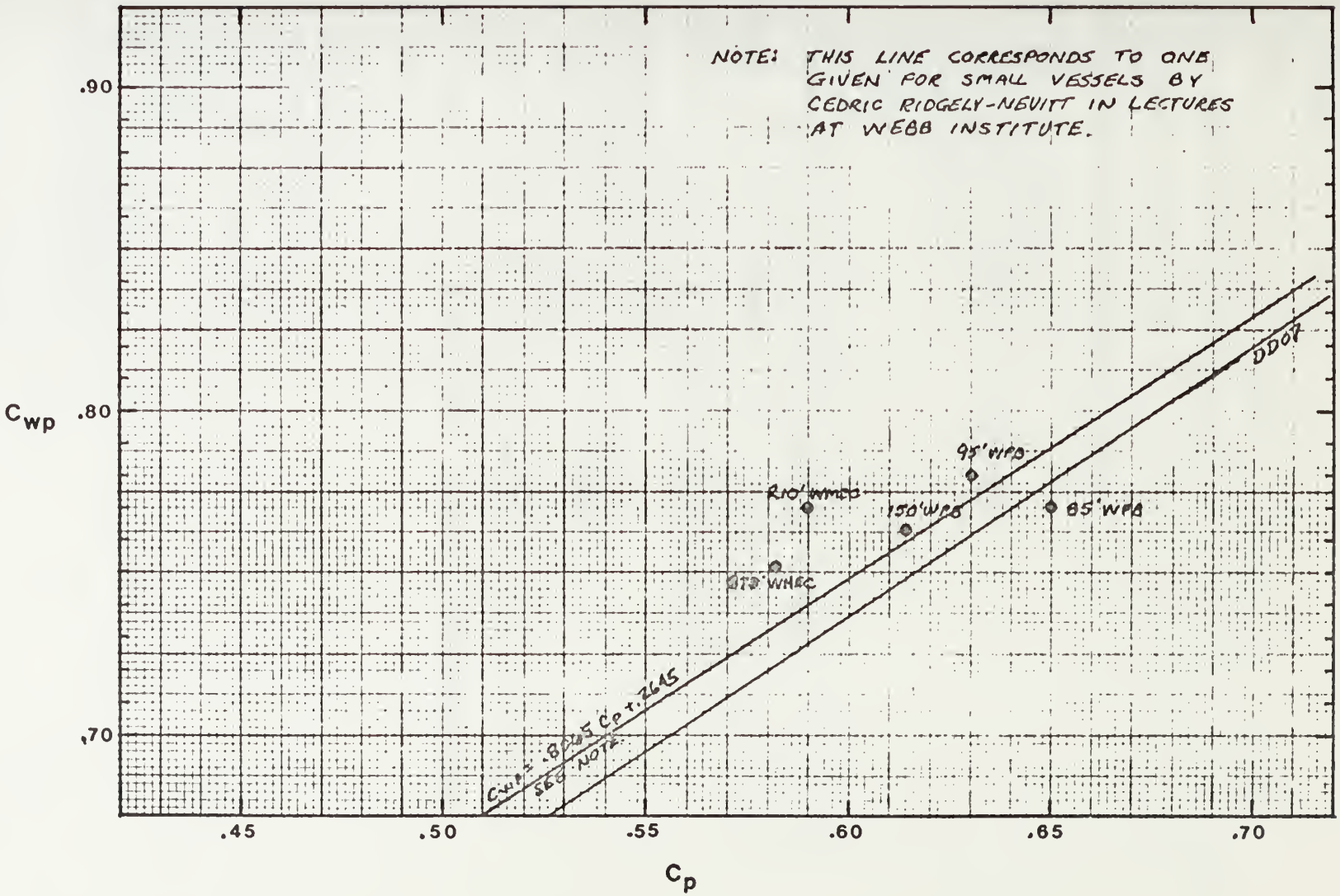

NOTE: THIS LINE CORRESPONDS TO ONE GIVEN FOR SMALL VESSELS BY CEDRIC RIDGELY-NEVITT IN LECTURES AT WEBB INSTITUTE.
.90
.80
.70
$C_{wp}$
.45
.50
.55
.60
.65
.70
$C_p$
DD07
95' WPB
82' WMEC
110' WMEC
150' WPB
85' WPB
$C_{WP} = .8 + .5\,C_p + .245$
SEE NOTE

Figure 8

```
      R=C2*HMIN+C3*BMIN**3-C4-C5*BMIN
      IF(R.LE.0) GOTO 2
      C4=C4-FRSC+R
      B1=BMIN
      H=HMIN
      RETURN
```

These statements compute the value of R if point 1 lies within the acceptable B/T limits. If R is positive, the program returns the value of beam and draft at point 1 and increases the estimate of KG by R.

```
    1 HMAX=SQRT(C1/2.005)
      BMIN=C1/HMAX
      R=C2*HMAX+C3*BMIN**3-C4-C5*BMIN
      IF(R.LE.0) GOTO 2
      C4=C4-FRSC+R
      B1=BMIN
      H=HMAX
      RETURN
```

These values are calculated for point 2 in Figure 7. Actually they are slightly off of point 2 to insure an acceptable value in the speed-power routine.

```
    2 HMIN=SQRT(C1/3.995)
      BMAX=C1/HMIN
      R=C2*HMIN+C3*BMAX**3-C4-C5*BMAX
      IF(R.LT.0.) GOTO 6
```

These values are calculated for point 4 in Figure 7. If R is negative at this point, an error message must be printed.

```
      A(1)=1.
      A(2)=-C4/C2
      A(3)=-C1*C5/C2
      A(4)=0.
      A(5)=C3/C2*C1**3
      B(1)=1.
      C(1)=1.
      Z=HMIN
    3 DO 4 I = 2,5
      B(I)=A(I)+Z*B(I-1)
    4 C(I)=B(I)+Z*C(I-1)
```

The columns of the Birge-Vieta method are calculated in these equations.

```
ZNEW=Z-B(5)/C(4)
IF(ABS(ZNEW-Z).LE..01*ZNEW) GOTO 5
Z=ZNEW
GOTO 3
```

A revised estimate of draft is calculated and the iteration is repeated unless the difference between the old and new values is less than 1 percent of the new estimate.

```
5 H=ZNEW
  B1=C1/H
  C4=C4-FRSC
  R=0.
  RETURN
```

The results are returned for point 3 in Figure 7.

```
6 LEN = -1000.
  RETURN
  END
```

These statements signal subroutine XECUTE to print an error message and proceed with a new data case.

### 3.4.4 Output List for Subroutine UWDIM

B1.....LC(GG)

CWP.....LC(GG)

H.....LC(GG)

### 3.4.5 Nomenclature List

All variables have the same definition as given in the MAIN program nomenclature except for the following:

| | |
|---|---|
| A(5) | column 1 of the Birge-Vieta method |
| B(5) | column 2 of the Birge-Vieta method |

Nomenclature List (cont)

| | |
|---|---|
| B1 | Beam, same as B in MAIN |
| BMAX | dummy value of beam |
| BMIN | dummy value of beam |
| BTR | beam to draft ratio |
| C(5) | column 3 in of the Birge-Vieta method |
| C1 | coefficient, see text |
| C2 | coefficient, see text |
| C3 | coefficient, see text |
| C4 | KG or KG + FRSC, feet |
| C5 | GMMUL in MAIN |
| CALPH | coefficient, see text |
| DISPL | DPTRY in MAIN |
| HMAX | dummy value of draft |
| HMIN | dummy value of draft |
| I | index variable |
| R | KB + BM - GM - KG - FRSC |
| Z | dummy value of draft |
| ZNEW | dummy value of draft |

## 3.5 Subroutine HPCALC

### 3.5.1 Introduction

Subroutine HPCALC performs a Taylor's Standard Series power estimation.[7] The procedure used is very similar to the hand calculating procedure. However, two problems are of interest with regard to doing the calculations on a computer. First, the $C_r$ curves plotted in Reference (7) must be converted to array form and stored in the program. Subroutine CRVAL, described in Section 3.6, chooses the correct value of $C_r$ from this stored array. Second, the surface area of the hull must be estimated.

One approximate formula for wetted surface is:

$S = 1.7 \cdot L \cdot T + V/T$ [3]

where L is the ship length

T is the draft

V is the volume of displacement

This form was used as a starting point and an empirical relationship was derived to bring the wetted surface more closely in line with that specified on the curves given in Reference (7). To do this a number of points were chosen on the curves given. These points were compared to the above formula and some correcting factors for B/T, $C_v$ and $C_p$ were added to reduce the difference. The formula given below gives values within 5 percent of the values calculated from the curves of Reference (7) over the entire range.

$$S = (1.7 \cdot L \cdot T + V/T)(.0053(B/T)^2 - .02(B/T) + 3 \cdot C_v + .08 \cdot C_p + .926)$$

This formula is probably not the best method for estimating the surface area. One method would be to convert the curves to arrays and interpolate to find the correct area. Such a method requires much more time and compute storage to produce a result only slightly better than this formula. Most of the error between a power calculated by this routine and by hand is probably due to error in the surface area prediction.

A flow chart for this routine is given in Figure 9.

3.5.2 Input List for HPCALC Subroutine

B.....LC(GG)

CP.....LC(GG)

DELCF.....LC(CC)

DPTRY.....LC(GG)

H.....LC(GG)

LEN.....LC(BB)

PC.....SCDA

VK.....SCDA

3.5.3 Statement Descriptions

DISPL=DPTRY/1.014

DISPL is the molded displacement. It is assumed that the total displacement is 1.4 percent greater than the molded displacement.

```
VOL=DISPL*35.
BDR=B/H
RN=VK*LEN*132050.
CF=.075/(ALOG10(RN)-2.)**2+DELCF
SLRAT=VK/(SQRT(LEN))
CV=VOL/(LEN)**3
```

# HPCALC SUBROUTINE FLOW CHART

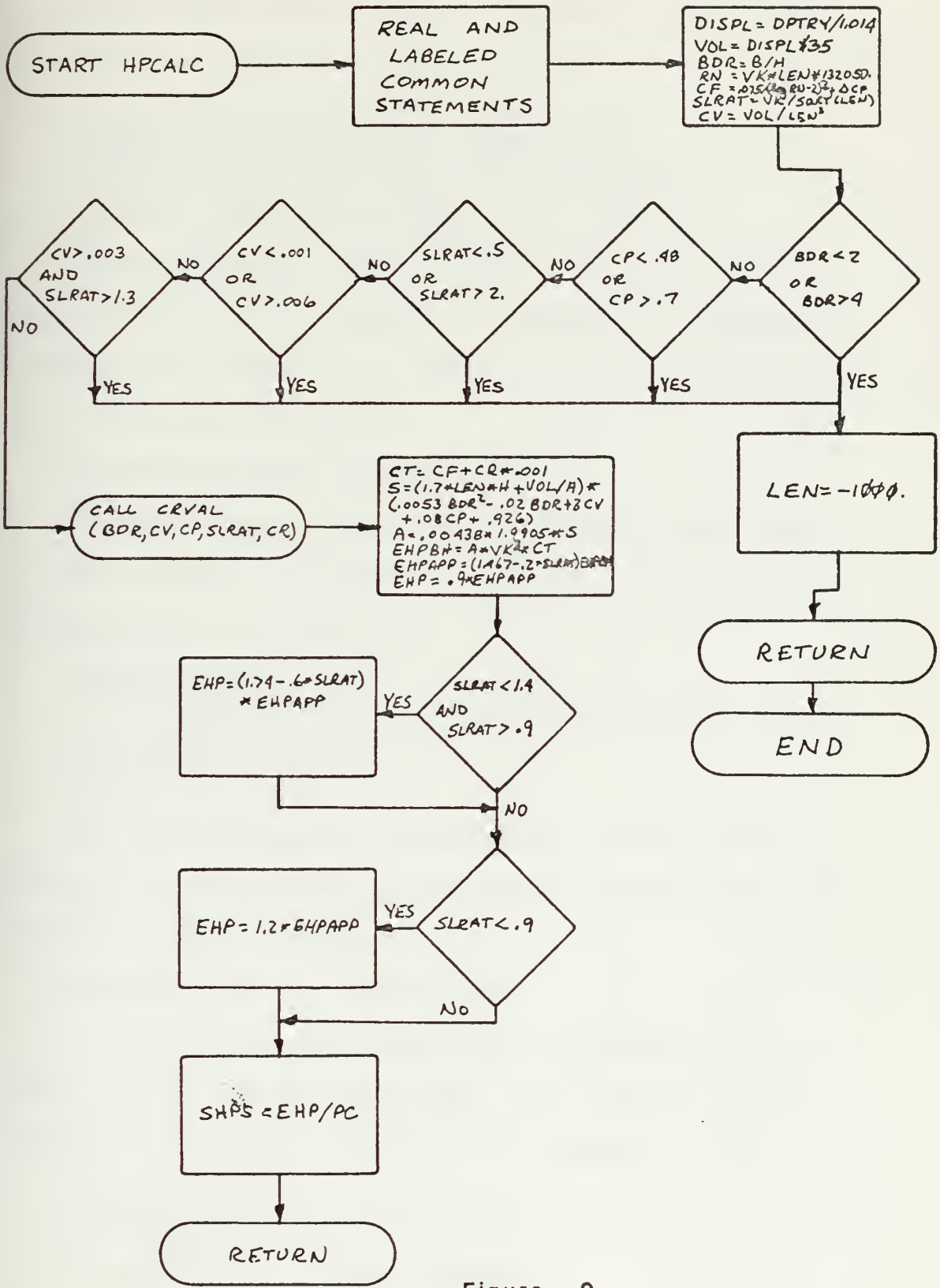



Figure 9

These formulas calculate, respectively, volume of displacement, beam to draft ratio, Reynold's number, $C_f$, speed length ratio, and $C_v$. $C_f$ is the coefficient of frictional resistance calculated based on the ITTC line.

```
IF(BDR.LT.2..OR.BDR.GT.4.) GOTO 1000
IF(CP.LT..48.OR.CP.GT..7) GOTO 1000
IF(SLRAT.LT..5.OR.SLRAT.GT.2.) GOTO 1000
IF(CV.LT..001.OR.CV.GT..006) GOTO 1000
IF(CV.GT..003.AND.SLRAT.GT.1.3) GOTO 1000
```

These statements check to make sure none of the constraints of the $C_r$ array are violated. If any is violated, the program will write an error message and go to the next input case.

```
CALL CRVAL(BDR,CV,CP,SLRAT,CR)
```

This subroutine is called to determine the value CR, the residuary resistance coefficient. The routine is described in section 3.6.

```
CT=CF+CR*.001
S=(1.7*LEN*H+VOL?H)*(.0053*BDR*BDR-.02*BDR+3.*CV+
     .08*CP+.926)
A=.00438*1.9905*S
EHPBH=A*VK**3*CT
```

The total resistance coefficient, wetted surface and finally the bare hull effective horsepower are calculated in these statements.

```
EHPAPP=(1.467-.2*SLRAT)*EHPBH
```

The effective horsepower with appendages has been based on data for the 378' WHEC. This data is shown in Figure 10 together with the above approximation.

```
EHP=.9*EHPAPP
IF(SLRAT.LT.1.4.AND.SLRAT.GT..9)EHP=(1.74-.6*SLRAT)*
     EHPAPP
IF(SLRAT.LE..9) EHP=1.2*EHPAPP
```

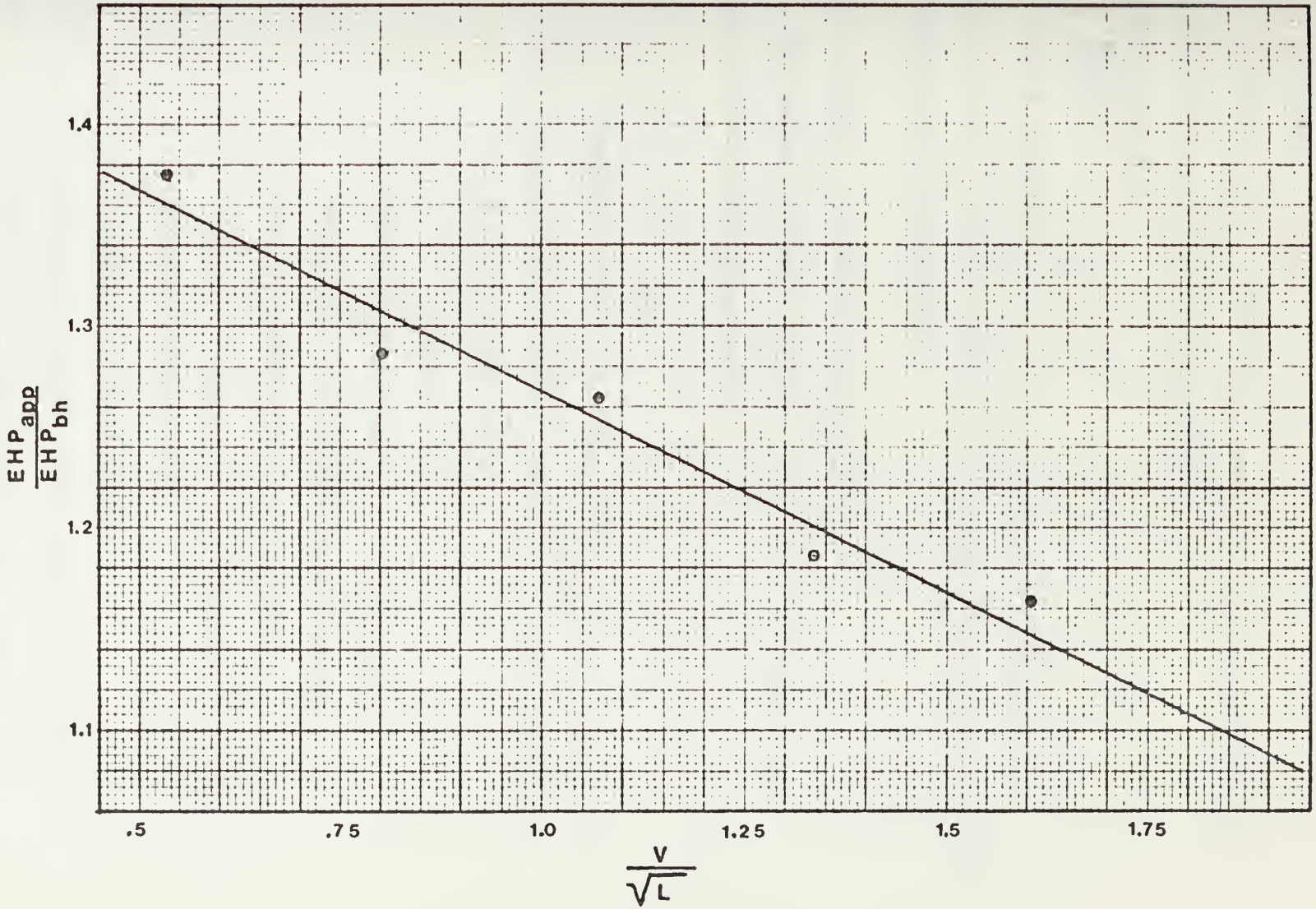



Figure 10

These equations approximate the $EHP/EHP_{Taylor}$ curve for the 378' WHEC as shown in Figure 11.

```
      SHP=EHP/PC
      RETURN
```

Finally, the shaft horsepower is calculated using the input propulsive coefficient.

```
1000  LEN= -1000.
      RETURN
      END
```

If a constraint of the $C_r$ array is violated the value of LEN is made negative to signal subroutine XECUTE to write an error message.

### 3.5.4 Output for Subroutine HPCALC

The only output is SHPS, which is returned as a call statement dummy argument.

### 3.5.5 Nomenclature List

All variables have the same definition as given in the MAIN program nomenclature except for the following:

| | |
|---|---|
| A | dummy coefficient |
| BDR | beam to draft ratio |
| CF | frictional resistance coefficient |
| CR | residuary resistance coefficient |
| CT | total resistance coefficient |
| CV | Taylor's volumetric coefficient |
| DISPL | molded displacement |
| EHP | effective horsepower |
| EHPAPP | effective horsepower with appendages |
| EHPBH | effective horsepower bare hull |

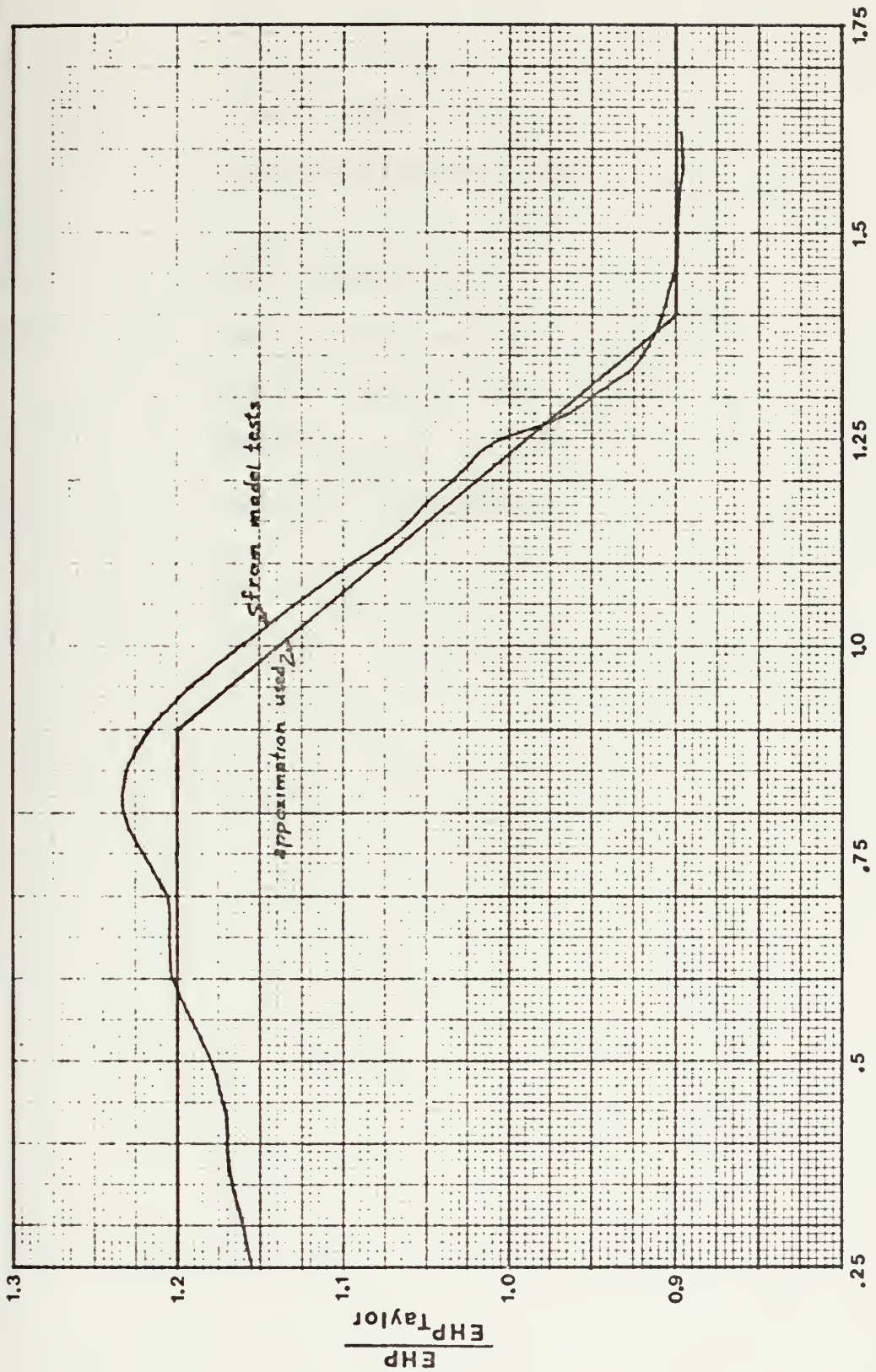

1.3
1.2
1.1
1.0
0.9
EHP / EHP Taylor
.25
.5
.75
1.0
1.25
1.5
1.75
V / √L
from model tests
approximation used

Figure 11

Nomenclature List (cont)

| | |
|---|---|
| PC | propulsive coefficient |
| RE | same as RGEND in MAIN |
| RN | Reynold's number |
| S | wetted surface, sq ft |
| SFCH | same as SFCHHP in MAIN |
| SFCM | same as SFCMHP in MAIN |
| SHPS | shaft horsepower |
| SLRAT | speed length ratio |
| VE | same as VEND in MAIN |
| VK | speed in knots |
| VOL | volume of displacement |

## 3.6 Subroutine CRVAL

### 3.6.1 Introduction

Although this routine is physically one of the longest in the cutter model, the job it performs is one of the simplest. Its only function is to choose from stored data arrays the values of the residuary resistance coefficient, $C_r$, which straddle the input point and then to interpolate to find the value of $C_r$ at the input point. The input point is specified by four variables. The value of each of these four-beam to draft ratio, $C_p$, $C_v$, and speed length ratio-is specified as input to the routine.

The constants stored in the three arrays which contain the $C_r$ data were determined using the curves given in Reference (7). Although the three arrays - CR1, CR2, and CR3 - are each one dimensional, the data they contain is four dimensional, varying with each of the four variables which specify the input point. Each of the arrays contains values for beam to draft ratios of 2.25, 3.0, and 3.75. For each beam to draft ratio $C_p$ was varied from 0.48 to 0.70 in steps of 0.02. For each of these values of B/T and $C_p$, all the possible combinations of $C_v$ and speed length ratio given below were stored.

In array CR1 is stored data for $C_v$ values of 0.001 and 0.002 and speed length ratios of 0.5 to 2.0 in steps of 0.1. Array CR2 corresponds to $C_v$ values of 0.003,

0.004, and 0.005 plus speed length ratios from 0.5 to 1.3 in steps of 0.1. Data for a $C_v$ value of 0.006 and speed length ratios of 0.5 to 1.0 in steps of 0.1 is stored in CR3.

In each of the three arrays, the first element corresponds to the lowest value of each of the four input variables. Speed length ratio is increased most rapidly followed by $C_p$, $C_v$ and finally beam to draft ratio.

The limits of the $C_r$ arrays given above are extended somewhat by extrapolation. Beam to draft ratios between 2.0 and 4.0 are accepted. The limiting value on $C_v$ has been extended by 0.001 for speed length ratios between 1.0 and 2.0. The maximum ranges that are accepted are given below.

$$2.0 \leq B/T \leq 4.0$$

$$.48 \leq C_p \leq .70$$

$$.001 \leq C_v \leq .006 \quad \text{for } 0.5 \leq V/\sqrt{L} \leq 1.3$$

$$.001 \leq C_v \leq .003 \quad \text{for } 0.5 \leq V/\sqrt{L} \leq 2.0$$

Sixteen values of $C_r$ are required to straddle the input values of $B/T$, $C_p$, $C_v$, and $V/\sqrt{L}$. After these sixteen numbers have been chosen, the value of $C_r$ at the input point is found by interpolation. A total of fifteen interpolations are required, eight to select the correct speed length ratio, four to select the correct $C_p$, two to select the correct beam to draft ratio, and a final one to select the correct $C_v$.

Even with the extensions listed earlier, the constraints

on the combined $C_r$ array cause the major limitations of the cutter model. The $C_r$ array data is listed in Appendix D. A flow chart for this routine is shown in Figures 12a and 12b.

3.6.2 Input List for Subroutine CRVAL

BTR.....SCDA

CP.....SCDA

CR1(1152).....LC(TT)

CR2(972).....LC(TT)

CR3(216).....LC(TT)

CV.....SCDA

VL.....SCDA

3.6.3 Statement Descriptions

```
I1(J,K,L,M)=(K-1)*384+(J-1)*192+(L-1)*16+M
I2(J,K,L,M)=(K-1)*324+(J-3)*108+(L-1)*9+M
I3(J,K,L,M)=(K-1)*72+(L-1)*6+M
```

These are statement functions which convert the four dimensions - J, K, L, and M - into a single dimension for use with arrays CR1, CR2, and CR3 respectively.

```
IF(BTR.GE.3.) K1=2
IF(BTR.LT.3.) K1=1
K2=K1+1
```

An index is chosen in these statements for the beam to draft ratio below the input point and above the input point.

```
  CP1=.68
3 IF(CP-CP1+.0001) 1,2,2
1 CP1=CP1-.02
  GOTO 3
2 L1=IFIX((CP1-.46)*50.1)
  L2=L1+1
```

# CRVAL SUBROUTINE FLOW CHART

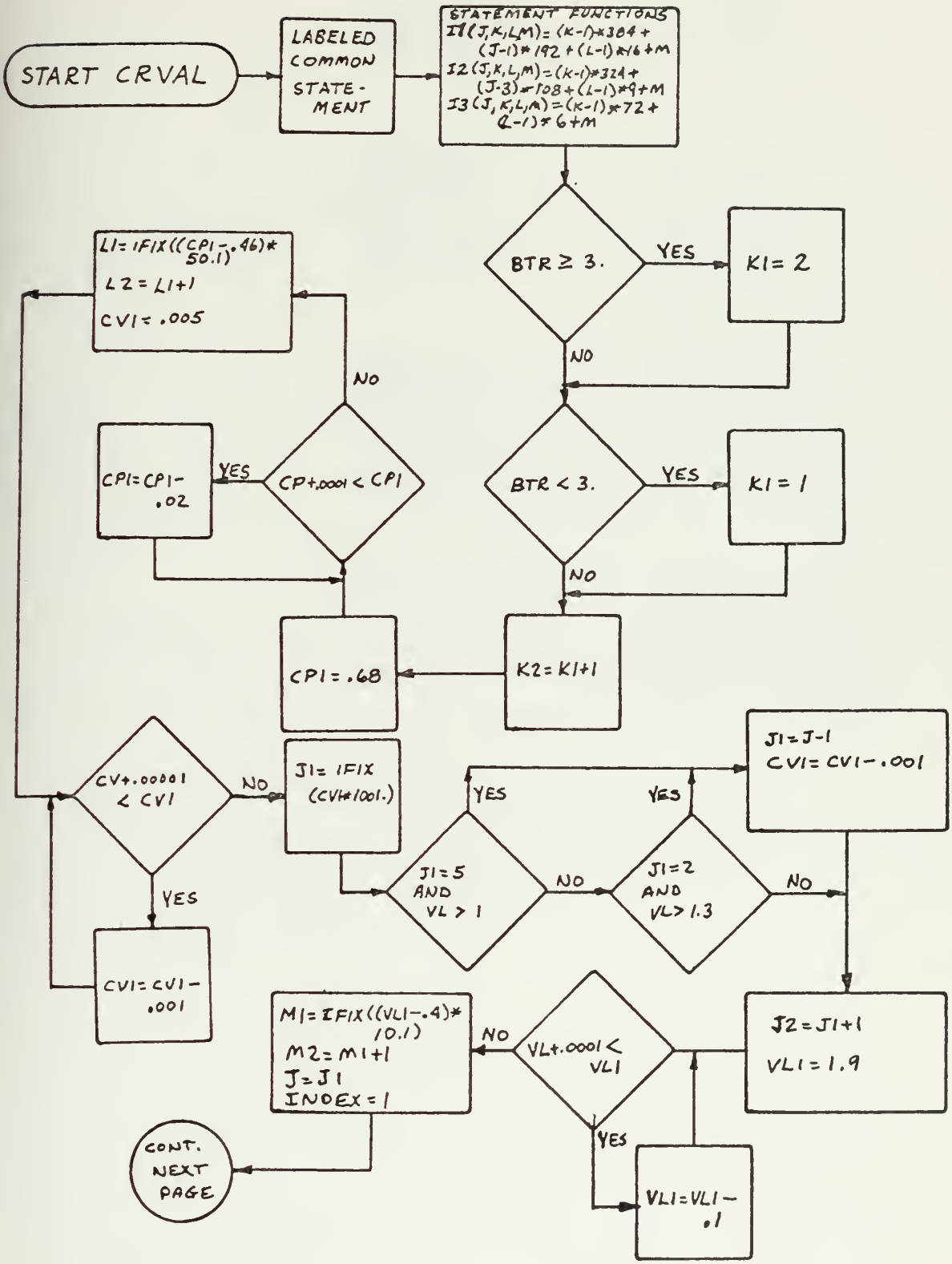



Figure 12a

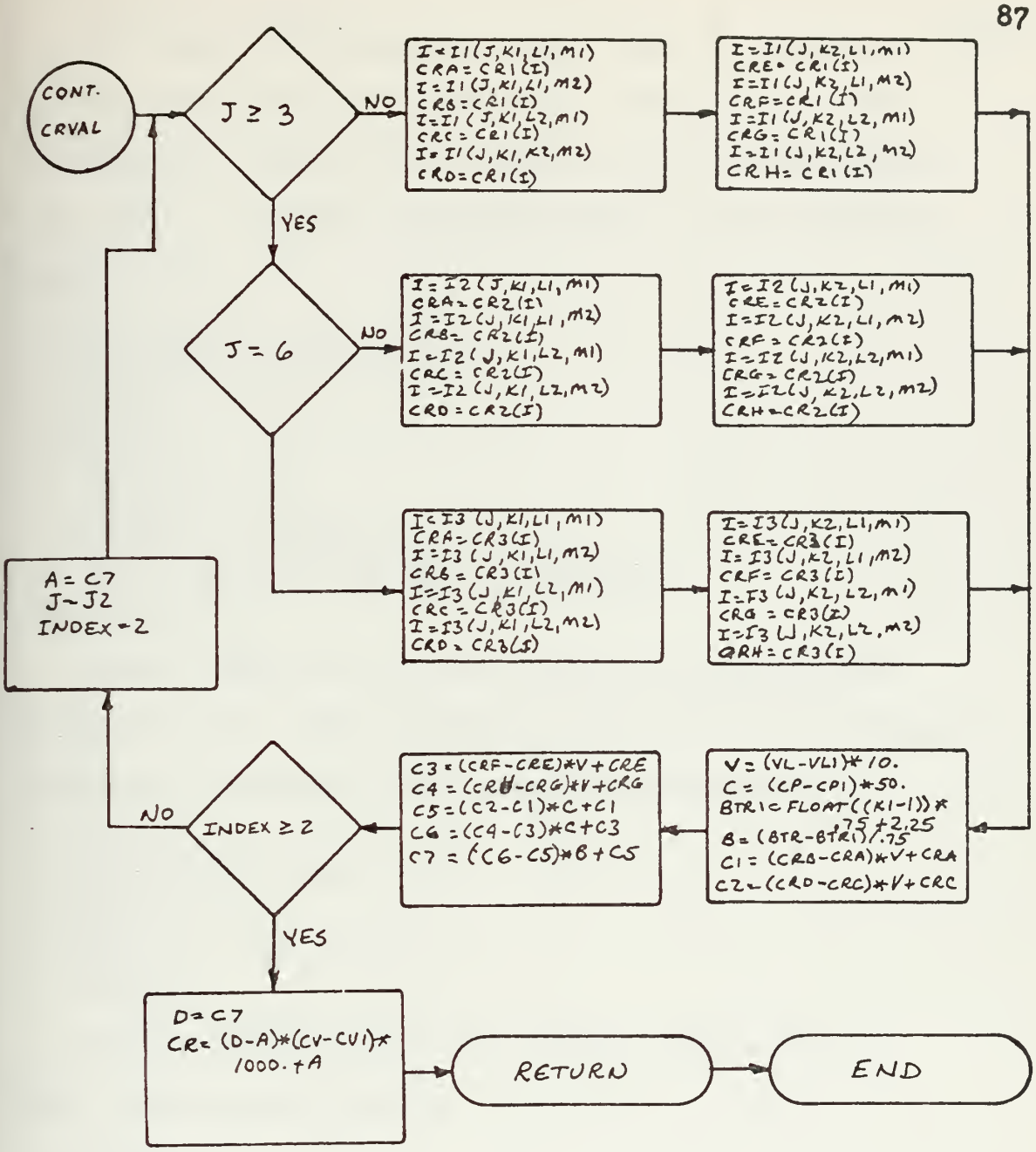

CONT.
CRVAL
J ≥ 3
NO
YES
I=I1(J,K1,L1,M1)
CRA=CR1(I)
I=I1(J,K1,L1,M2)
CRB=CR1(I)
I=I1(J,K1,L2,M1)
CRC=CR1(I)
I=I1(J,K1,L2,M2)
CRD=CR1(I)
I=I1(J,K2,L1,M1)
CRE=CR1(I)
I=I1(J,K2,L1,M2)
CRF=CR1(I)
I=I1(J,K2,L2,M1)
CRG=CR1(I)
I=I1(J,K2,L2,M2)
CRH=CR1(I)
J = 6
NO
I=I2(J,K1,L1,M1)
CRA=CR2(I)
I=I2(J,K1,L1,M2)
CRB=CR2(I)
I=I2(J,K1,L2,M1)
CRC=CR2(I)
I=I2(J,K1,L2,M2)
CRD=CR2(I)
I=I2(J,K2,L1,M1)
CRE=CR2(I)
I=I2(J,K2,L1,M2)
CRF=CR2(I)
I=I2(J,K2,L2,M1)
CRG=CR2(I)
I=I2(J,K2,L2,M2)
CRH=CR2(I)
I=I3(J,K1,L1,M1)
CRA=CR3(I)
I=I3(J,K1,L1,M2)
CRB=CR3(I)
I=I3(J,K1,L2,M1)
CRC=CR3(I)
I=I3(J,K1,L2,M2)
CRD=CR3(I)
I=I3(J,K2,L1,M1)
CRE=CR3(I)
I=I3(J,K2,L1,M2)
CRF=CR3(I)
I=I3(J,K2,L2,M1)
CRG=CR3(I)
I=I3(J,K2,L2,M2)
CRH=CR3(I)
A=C7
J=J2
INDEX=2
V=(VL-VL1)*10.
C=(CP-CP1)*50.
BTR1=FLOAT((K1-1))*.75+2.25
B=(BTR-BTR1)/.75
C1=(CRB-CRA)*V+CRA
C2=(CRD-CRC)*V+CRC
C3=(CRF-CRE)*V+CRE
C4=(CRH-CRG)*V+CRG
C5=(C2-C1)*C+C1
C6=(C4-C3)*C+C3
C7=(C6-C5)*B+C5
INDEX ≥ 2
NO
YES
D=C7
CR=(D-A)*(CV-CV1)*1000.+A
RETURN
END

Figure 12b

In these statements, an array index is chosen for the $C_p$ below and above the input point. The extra 0.0001 in statement 3 and the 50.1 instead of 50 in statement 2 are used to account for small errors in the computer calculations.

```
      CV1=.005
    4 IF(CV-CV1+.00001) 5,6,6
    5 CV1=CV1-.001
      GOTO 4
   13 J1=J1-1
      CV1=CV1-.001
      GOTO 14
    6 J1=IFIX(CV1*1001.)
      IF(J1.EQ.5.AND.VL.GT.1.) GOTO 13
      IF(J1.EQ.2.AND.VL.GT.1.3) GOTO 13
   14 J2=J1+1
```

Array indices for $C_v$ are chosen below and above the input point. The statements connected with statement 13 extend the limits of the array by extrapolation.

```
      VL1=1.9
    7 IF(VL-VL1+.0001) 8,9,9
    8 VL1=VL1-.1
      GOTO 7
    9 M1=IFIX((VL1-.4)*10.1)
      M2=M1+1
```

Again array indices are chosen, this time for speed length ratio values.

```
      J=J1
      INDEX=1
```

The value of $C_v$ is held fixed each time through the following statements. When $C_r$ values at each of the two $C_v$ values have been calculated, an interpolation is done to find the $C_r$ value at the correct $C_v$ value.

```
   11 IF(J.GE.3) GOTO 10
      I=I1(J,K1,L1,M1)
      CRA=CR1(I)
           .
           .
```

```
      .
      .
      .
     I=I1(J,K2,L2,M2)
     CRH=CR1(I)
     GOTO 50
```

Variables CRA to CRH are used for the eight $C_r$ values that remain when $C_v$ is held constant. In this set of statements array CR1 is used.

```
  10 IF(J.EQ.6)  GOTO 12
     I=I2(J,K1,L1,M1)
     CRA=CR2(I)
      .
      .
      .
     I=I2(J,K2,L2,M2)
     CRH=CR2(I)
     GOTO 50
```

This group of statements is identical to the proceeding group except that array CR2 is used.

```
  12 I=I3(J,K1,L1,M1)
     CRA=CR3(I)
      .
      .
      .
     I=I3(j,K2,L2,M2)
     CRH=CR3(I)
```

Again these statements are identical with array CR3 being used.

```
  50 V=(VL-VL1)*10.
     C=(CP-CP1)*50.
     BTR1=FLOAT((K1-1))*.75+2.25
     B=(BTR-BTR1)/.75
     C1=(CRB-CRA)*V+CRA
     C2=(CRD-CRC)*V+CRC
     C3=(CRF-CRE)*V+CRE
     C4=(CRH-CRG)*V+CRG
     C5=(C2-C1)*C+C1
     C6=(C4-C3)*C+C3
     C7=(C6-C5)*B+C5
```

These are the interpolation statements required to first calculate the value of $C_r$ at the input speed length ratio, then at the input $C_p$ and finally at the input beam to draft ratio.

```
      IF(INDEX.GE.2) GOTO 51
      A=C7
      J=J2
      INDEX=2
      GOTO 11
```

When INDEX = 1 the lower value of $C_v$ is used in the interpolation above. The next step is to do the interpolation at the upper value of $C_v$. The value of $C_r$ at the lower $C_v$ is saved as variable A.

```
   51 D=C7
      CR=(D-A)*(CV-CV1)*1000.+A
      RETURN
      END
```

One final interpolation is performed to calculate the desired value of CR and the routine returns control to subroutine HPCALC.

### 3.6.4 Output for Subroutine CRVAL

The only output is the calculated value of CR which is returned as a subroutine call dummy argument.

### 3.6.5 Nomenclature List

All variables have the same definition as given in the MAIN program nomenclature except for the following:

| | |
|---|---|
| A | $C_r$ value at lower $C_v$ value |
| B | fraction of BTR interval |
| BTR | input value of beam to draft ratio |
| BTR1 | lower value of beam to draft ratio |

| | |
|---|---|
| C | fraction of $C_p$ interval |
| C1 | $C_r$ at correct $V/\sqrt{L}$, lower BTR, lower $C_p$ |
| C2 | $C_r$ at correct $V/\sqrt{L}$, lower BTR, higher $C_p$ |
| C3 | $C_r$ at correct $V/\sqrt{L}$, higher BTR, lower $C_p$ |
| C4 | $C_r$ at correct $V/\sqrt{L}$, higher BTR, higher $C_p$ |
| C5 | $C_r$ at correct $V/\sqrt{L}$ and $C_p$, lower BTR |
| C6 | $C_r$ at correct $V/\sqrt{L}$ and $C_p$, higher BTR |
| C7 | $C_r$ at correct $V/\sqrt{L}$, $C_p$ and BTR |
| CP1 | lower $C_p$ value |
| CR | $C_r$ value at input point |
| CRA | $C_r$ at lower $V/\sqrt{L}$, $C_p$ and BTR |
| CRB | $C_r$ at higher $V/\sqrt{L}$, lower $C_p$ and BTR |
| CRC | $C_r$ at lower $V/\sqrt{L}$ and BTR, higher $C_p$ |
| CRD | $C_r$ at higher $V/\sqrt{L}$ and $C_p$, lower BTR |
| CRE | $C_r$ at lower $V/\sqrt{L}$ and $C_p$, higher BTR |
| CRF | $C_r$ at higher $V/\sqrt{L}$ and BTR, lower $C_p$ |
| CRG | $C_r$ at lower $V/\sqrt{L}$, higher BTR and $C_p$ |
| CRH | $C_r$ at higher $V/\sqrt{L}$, BTR, and $C_p$ |
| CV | input value of $C_v$ |
| CV1 | lower value of $C_v$ |
| D | $C_r$ value at upper $C_v$ value |
| I | array index |
| INDEX | Indicates whether $C_v$ is at lower or upper value |
| J | used for either J1 or J2 |
| J1 | index for lower value of $C_v$ |
| J2 | index for higher value of $C_v$ |
| K1 | index for lower value of BTR |

| | |
|---|---|
| K2 | index for higher value of BTR |
| L1 | index for lower value of $C_p$ |
| L2 | index for higher value of $C_p$ |
| M1 | index for lower value of $V/\sqrt{L}$ |
| M2 | index for higher value of $V/\sqrt{L}$ |
| V | fraction of $V/\sqrt{L}$ interval |
| VL | input speed length ratio |
| VL1 | lower value of speed length ratio |

## 3.7 Subroutine EPLANT

### 3.7.1 Introduction

This routine performs two functions. The first is to estimate an average plant electrical load for use in calculating fuel requirements. The second is to size the generators. Generator size is used primarily for estimating weights, but it is also a useful output which provides information needed for beginning the preliminary design phase.

Three ships were used in developing electrical load relations. These were the 378' WHEC, the 210' WMEC, and the 150' WPB. The electrical loads for these vessels were categorized as shown in Table 1. This table also gives the loads in KW that were used.

The first two categories, electronics load and armament load, are inputs. Propulsion auxiliary load includes only equipment needed for the direct operation of the main propulsion machinery. For example, lub oil service pumps are included in this category but lub oil transfer pumps are included under other auxiliaries. Air conditioning and ventilation also includes electric heaters. Hotel is primarily galley and lighting.

Estimating relationships were developed for each of the last four categories in Table 1. If the propulsion auxiliary load is not input, a value of 1 KW is assumed for diesel plants and 71 KW for CODOG plants. Air conditioning and ventilation is calculated as a function

Table 1

ELECTRICAL LOAD REQUIREMENTS

| Electrical Load | 150' WPB | 210' WMEC | 378' WHEC |
|---|---|---|---|
| Electronics | 4.8 | 21.99 | 117.84 |
| Armament | 42.7 | 0.0 | 46.64 |
| Propulsion Aux. | 1.02 | .71 | 71.03 |
| Air Cond. & Vent. | 21.1 | 49.13 | 308.34 |
| Hotel | 20.9 | 35.4 | 170.51 |
| Steering gear | .54 | 4.48 | 37.38 |
| Aux. Machinery | 18.26 | 40.08 | 70.72 |
| Shops | 1.0 | 2.2 | 4.98 |
| Other Aux.(total) | 19.8 | 46.76 | 113.08 |
| Total | 110.32 | 153.99 | 827.44 |

All loads are in KW

of cubic number times the number of accommodations. Hotel load is a function of the number of accommodations only. Other auxiliaries load is assumed to be a function of cubic number only. These relationships are plotted in Figures 14, 15 and 16.

The total electrical load required is equal to the sum of the six categories above with a two percent growth margin on all equipment plus a 100 percent margin on electronics. An additional 25 percent is included above the growth margin to allow for deterioration and starting loads.

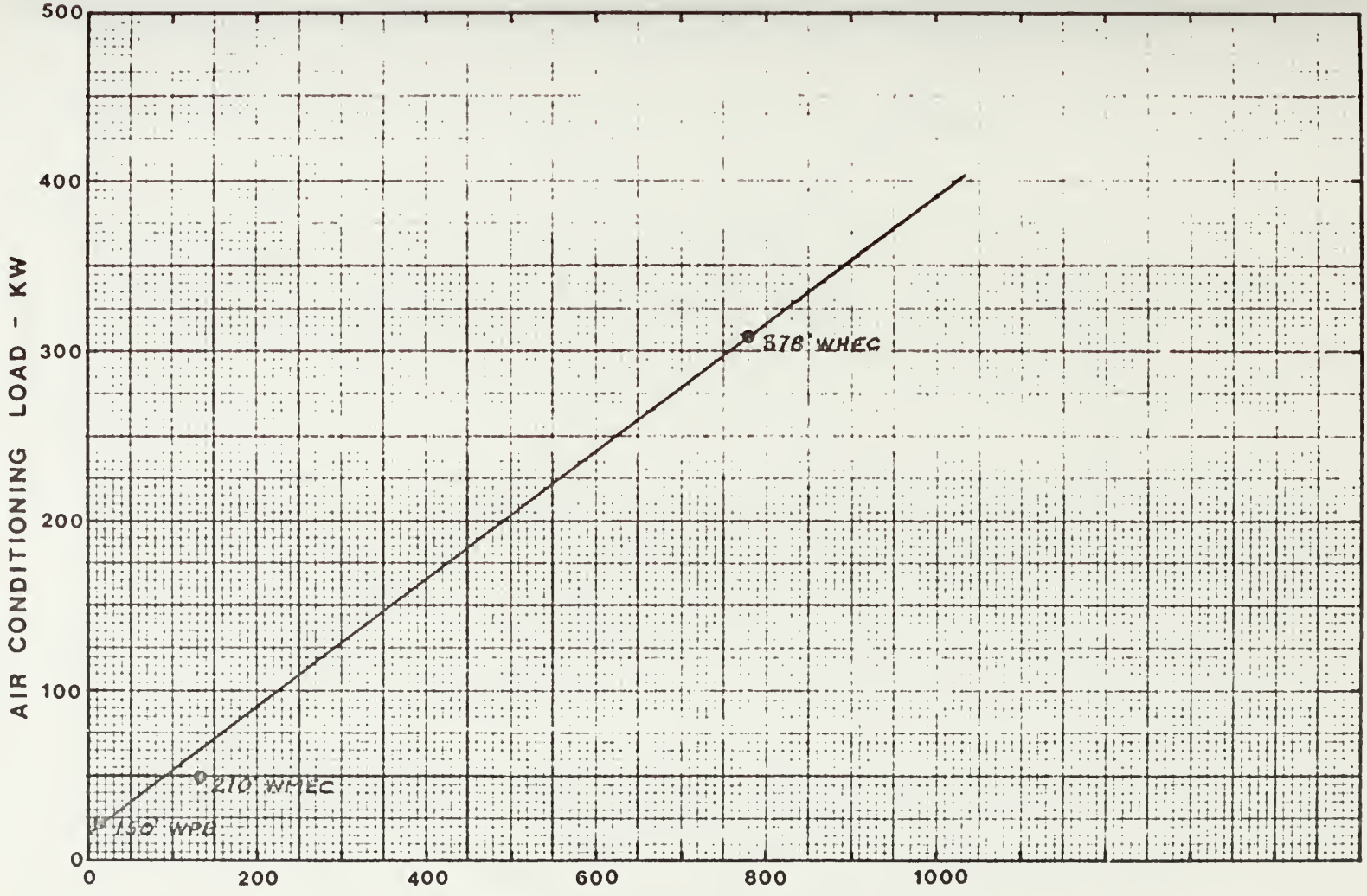

AIR CONDITIONING LOAD - KW
500
400
300
200
100
0
0
200
400
600
800
1000
878' WHEC
210' WHEC
150' WPB
NAC x CN x $10^{-5}$

Figure 14

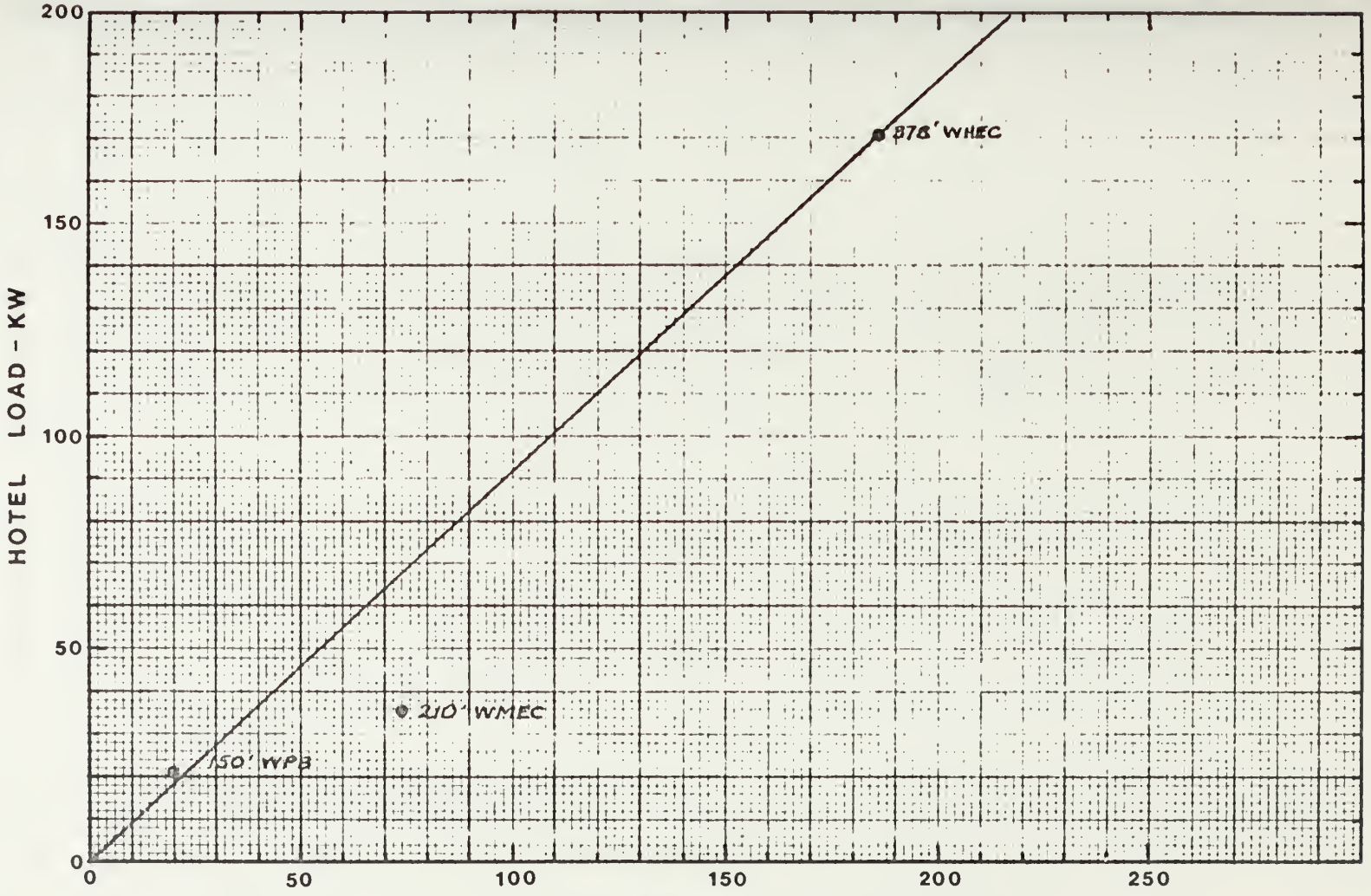

HOTEL LOAD - KW
200
150
100
50
0
0
50
100
150
200
250
NO. of ACCOMMODATIONS
378' WHEC
210' WMEC
150' WPB

Figure 15

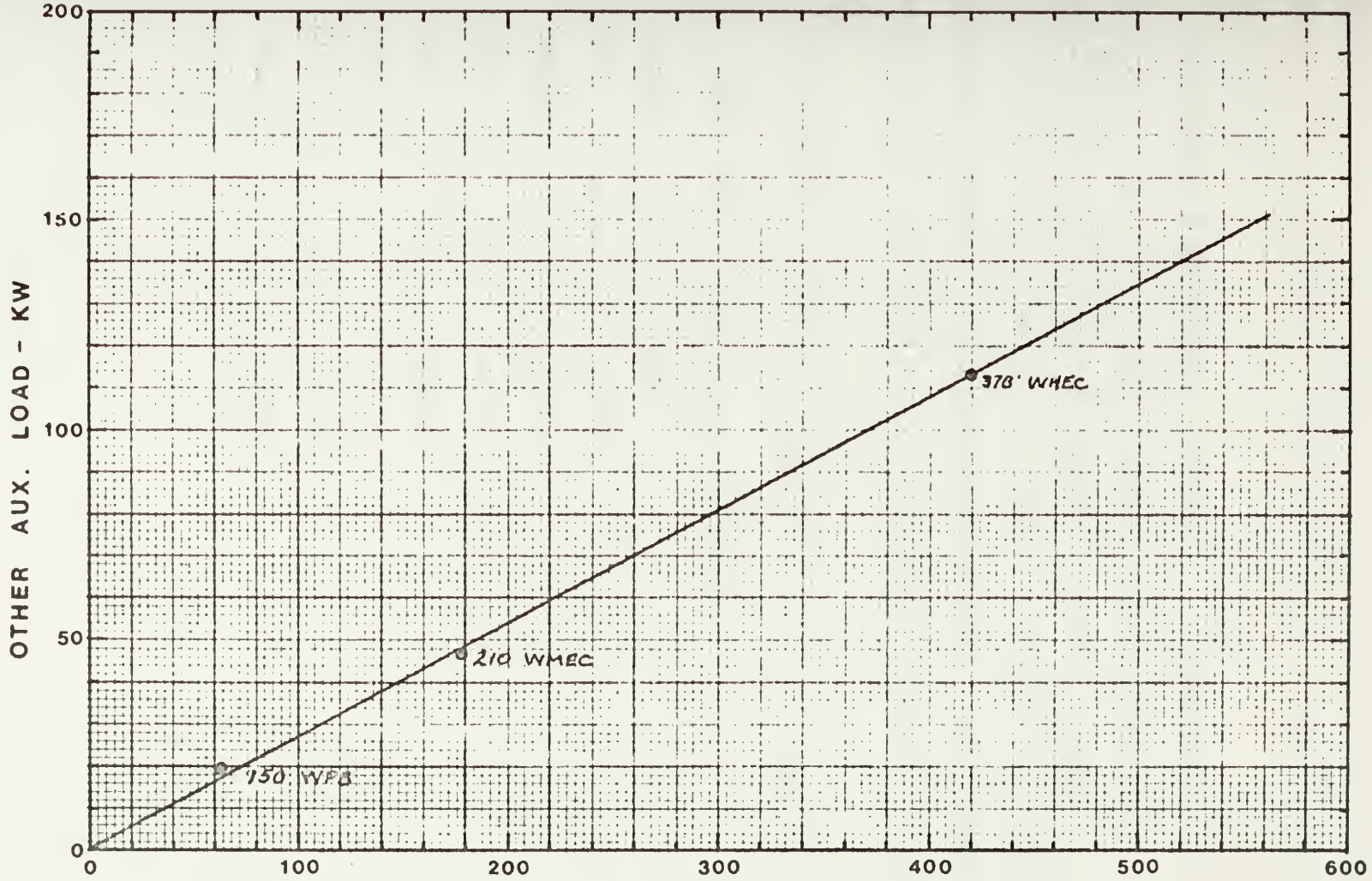

OTHER AUX. LOAD - KW
200
150
100
50
0
0
100
200
300
400
500
600
CUBIC NUMBER x $10^{-3}$ (CU FT)
378' WHEC
210 WMEC
150 WPB

Figure 16

It is assumed that three generators will be installed. Each generator is sized so as to be able to carry the full electrical load. This represents the current Coast Guard practice for new designs. Less capacity has been installed on past designs.

The smallest generator that will be installed is assumed to be 100 KW. Other possible plant sizes lie between 100 KW and 250 KW in steps of 50 KW, between 250 KW and 1000 KW in steps of 250 KW, and above 1000 KW in steps of 500 KW. The smallest generator that is able to supply the total load with the margins stated above is chosen.

A flow chart for this routine is shown in Figure 17.

3.7.2 Input List for Subroutine EPLANT

BLOAD.....LC(DD)

CN.....LC(BB)

ELOAD.....LC(DD)

JOPT.....LC(CC)

MTYPE.....LC(CC)

NCPO.....LC(AA)

NENL.....LC(AA)

NOFF.....LC(AA)

PALOAD.....LC(DD)

# EPLANT SUBROUTINE FLOW CHART

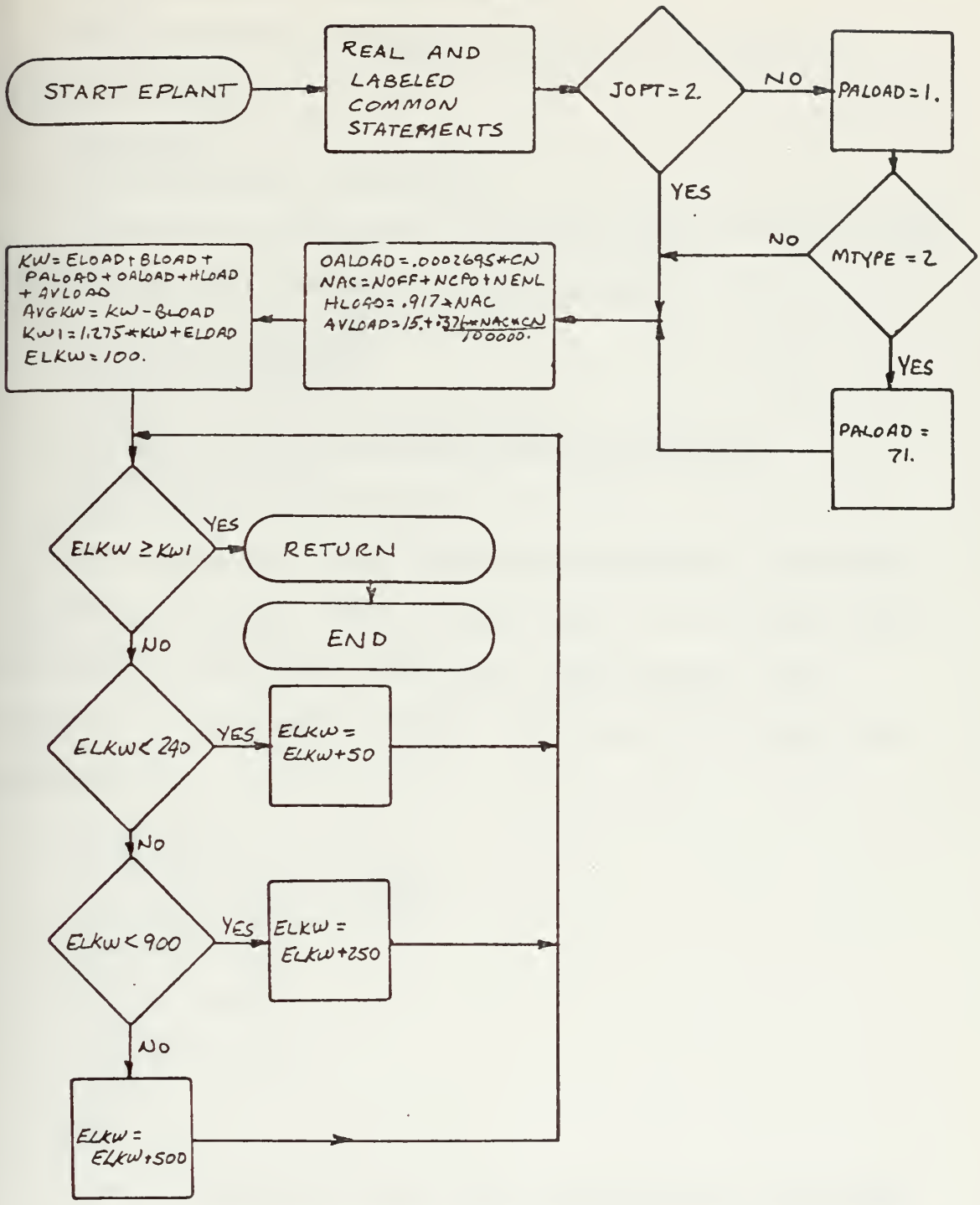



Figure 17

3.7.3 Statement Descriptions

```
      IF(JOPT.EQ.2) GOTO 1
```

The estimate of PALOAD is skipped if a value is given as input.

```
      PALOAD=1.
      IF(MTYPE.EQ.2) PALOAD=71.
```

Propulsion auxiliaries electrical load is calculated for diesel and CODOG plants respectively.

```
    1 OALOAD=.0002695*CN
      NAC=NOFF+NCPO+NENL
      HLOAD=.917*NAC
      AVLOAD=15.+.376*NAC*CN/100000.
      KW=ELOAD+BLOAD+PALOAD+OALOAD+HLOAD+AVLOAD
      AVGKW=KW-BLOAD
      KW1=1.25*(1.02*KW+ELOAD)
```

The individual load items are calculated and summed to give an estimate of the total load. The average load is taken as the total load minus the armament load. Margins are then added to the total load for sizing the generators.

```
      ELKW=100.
    2 IF(ELKW.GE.KW1) GOTO 3
      IF(ELKW.LT.240.) GOT 4
      IF(ELKW.LT.900.) GOTO 5
      ELKW=ELKW+500.
      GOTO 2
    4 ELKW=ELKW+50.
      GOTO 2
    5 ELKW=ELKW+250.
      GOTO 2
    3 RETURN
      END
```

These statements choose the generator rating, ELKW, which is the next size larger than the total load with margins.

3.7.4 Output List for Subroutine EPLANT

AVGKW.....LC(DD)

ELKW.....LC(DD)

3.7.5 Nomenclature List

All variables have the same definition as given in the MAIN program nomenclature except for the following:

| | |
|---|---|
| AVLOAD | air conditioning and ventilation load, KW |
| HLOAD | hotel load, KW |
| KW | total load without margins, KW |
| KW1 | total load with margins, KW |
| NAC | number of accommodations |
| OALOAD | other auxiliaries load, KW |
| RE | same as RGEND in MAIN |
| SFCH | same as SFCHHP in MAIN |
| SFCM | same as SFCMHP in MAIN |
| VE | same as VEND in MAIN |

## 3.8 Subroutine MACHLQ

### 3.8.1 Introduction

At this point in the program, the shaft horsepower and size of the electrical plant have been determined and the weight of fuel, lub oil and potable water can be calculated. Subroutine MACHLQ performs these calculations. In conjunction with the fuel weight calculations, the specific fuel consumption, SFC, at endurance power is estimated.

For diesel plants it is assumed that the SFC at rated power is 0.42 lbs/shp-hr and at one half rated power is 0.46 lbs/shp-hr. A linear relation is used for other power ratios. The SFC used for CODOG plants is 0.42 if the endurance power is less than 7000 SHP. This assumes that the diesels will be sized to be at maximum power at endurance speed. If the endurance power requirements are greater than 7000 SHP, the gas turbines must be used at endurance speed. Three maximum power levels for the gas turbines are used - 25000 HP, 35000 HP and 50000 HP. At each of these horsepower levels the SFC is taken to be 0.50 lbs/shp-hr. At half power, the SFC is .595. A linear relation is used for other power levels.

If a specific machinery plant is input, the specific fuel consumptions at half and full power are given. A linear relation is used for other power levels.

The specific fuel consumption of the ship service generators is assumed to be about 0.48 lbs/shp-hr or 0.65 lbs/KW-hr. The generator fuel consumption is computed using the average electrical load.

Fuel consumption for hotel services is taken to be 0.32 lbs/man-hr. This assumes some waste heat recovery.

The lub oil requirements for diesels is assumed to be 5 tons plus 1 ton per thousand horsepower. For CODOG plants this same relationship is used for the diesel part of the plant (endurance power is used in computing the requirements). However, additional lub oil for the gas turbines is included. For the gas turbines, the oil requirements are 3.5 tons plus 1 ton per ten thousand horsepower.

Potable water requirements are taken to be 50 gal/man or 0.186 tons/man. A flow chart for this routine is shown in Figure 18.

3.8.2 Input List for Subroutine MACHLQ

| | |
|---|---|
| AVGKW.....LC(DD) | RE.....LC(CC) |
| JOPT.....LC(CC) | SFCH.....LC(CC) |
| MTYPE.....LC(CC) | SFCM.....LC(CC) |
| NCPO.....LC(AA) | SHPE.....LC(CC) |
| NENL.....LC(AA) | SHPM.....LC(CC) |
| NOFF.....LC(AA) | VE.....LC(CC) |

# MACHLQ SUBROUTINE FLOW CHART

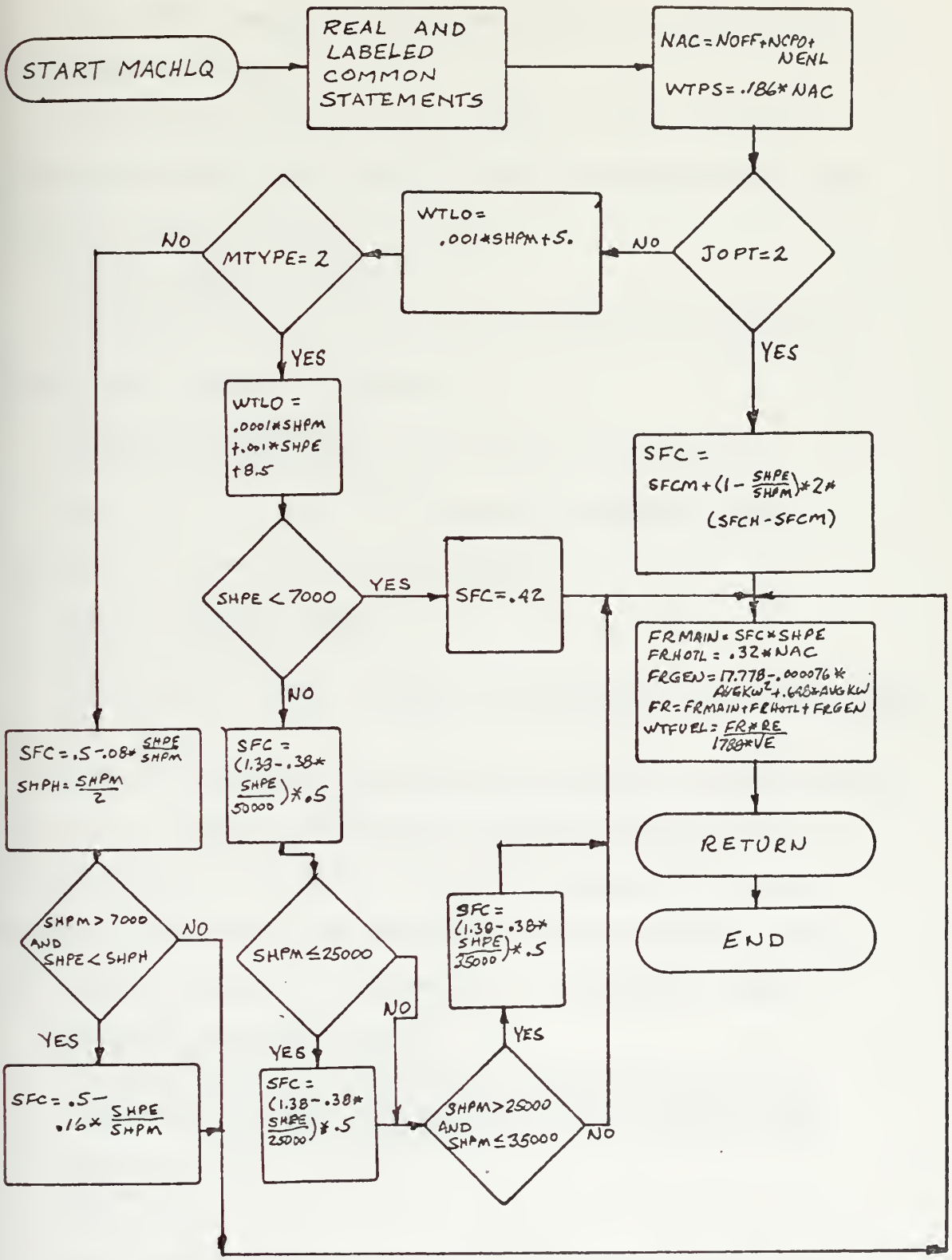



Figure 18

3.8.3 Statement Descriptions

```
NAC=NOFF+NCPO+NENL
```

The total number of accommodations is calculated.

```
WTPS=.186*NAC
```

Additional items will be added to the weight of personnel stores later but for now it includes only the weight of potable water.

```
IF(JOPT.EQ.2) GOTO 1
```

This skips the lub oil and standard SFC estimates since these values are inputs.

```
WTLO=.001*SHPM+5.
IF(MTYPE.EQ.2) WTLO=.0001*SHPM+.001*SHPE+8.5
```

The lub oil weight for diesel and CODOG plants respectively are calculated here.

```
IF(MTYPE.EQ.2) GOTO 2
SFC=.5-.08*SHPE/SHPM
SHPH=SHPM/2.
IF(SHPM.GT.7000..AND.SHPE.LT.SHPH)SFC=.5-.16*SHPE/SHPM
GOTO 3
```

These statements calculate the SFC for diesel plants. In case the shaft horsepower is greater than 7000 it is assumed that four diesels will be installed. If the endurance power is less than half of the maximum, only two diesels need be in operation at endurance speed.

```
  2 IF(SHPE.LT.7000.) GOTO 4
    SFC=(1.38-.38*SHPE/50000.)*.5
    IF(SHPM.LE.25000.)SFC=(1.38-.38*SHPE/25000.)*.5
    IF(SHPM.GT.25000..AND.SHPM.LE.35000.) SFC=(1.38-
                .38*SHPE/35000.)*.5
    GOTO 3
  4 SFC=.42
    GOTO 3
```

For CODOG plants the SFC is calculated using the

statements above.

```
1 SFC=SFCM+(1.-SHPE/SHPM)*2.*(SFCH-SFCM)
```

If SFCH and SFCM are input, the above linear relation is used for calculating the SFC at endurance speed.

```
3 FRMAIN=SFC*SHPE
  FRHOTL=.32*NAC
  FRGEN=.65*AVGKW
  FR=FRMAIN+FRHOTL+FRGEN
```

All of these fuel rates are in lbs/hr.

```
  WTFUEL=FR*RE/(1788.*VE)
  RETURN
  END
```

The factor 1788. is derived from:

$$\frac{2240.*(1 - F_{tp})}{F_m * F_{deg} * F_{sc}}$$

where:

$F_{tp}$ = .05 is a tailpipe allowance

$F_m$ = 1.03 is an extra margin

$F_{deg}$ = 1.05 is a degradation allowance

$F_{sc}$ = 1.10 is an allowance for sea conditions and fouling

The value 2240 converts pounds to tons.

### 3.8.4 Output List for Subroutine MACHLQ

WTFUEL.....LC(LL)

WTLO.....LC(LL)

WTPS.....LC(LL)

### 3.8.5 Nomenclature List

All variables have the same definition as given in the MAIN program nomenclature except for the following:

Nomenclature List (cont)

| | |
|---|---|
| FR | total fuel rate in lbs/hr |
| FRGEN | generator fuel rate in lbs/hr |
| FRHOTL | hotel fuel rate in lbs/hr |
| FRMAIN | main engine fuel rate in lbs/hr |
| NAC | total number of accommodations |
| RE | same as RGEND in MAIN |
| SFC | specific fuel consumption at endurance power |
| SFCH | same as SFCHHP in MAIN |
| SFCM | same as SFCMHP in MAIN |
| SHPH | one half maximum shaft horsepower |
| VE | same as VEND in MAIN |

## 3.9 Subroutine MBSIZE

### 3.9.1 Introduction

Very little data is available concerning the minimum allowable depth and length of the machinery compartment. As a result, only very simple calculations are made in this subroutine to estimate these two dimensions.

The product of length of machinery box times the maximum beam of the ship was calculated for two diesel designs, the 210' WMEC and the 150' WPB, and for one CODOG plant, the 378' WHEC. A value of about 1050 sq. ft. was obtained for both diesel designs and a value of 2300 sq. ft. was obtained using the CODOG plant. These values are divided by the beam of the ship to obtain the required engine room length in the program.

A check is also made to insure that a minimum length is not exceeded. This minimum length was taken to be 28 feet or 56 feet for diesel plants below or above 7000 BHP respectively and 45 feet for a CODOG plant.

A rough deck height approximation was derived using data from the same three vessels mentioned above. The formula used gives a deck height of about 17 feet for the 150' WPB and about 19 feet for the 210' WMEC. The deck height for all plants with horsepowers greater than 7000 is taken as 22 feet.

A flow chart for this subroutine is shown in Figure 19.

## MBSIZE SUBROUTINE FLOW CHART

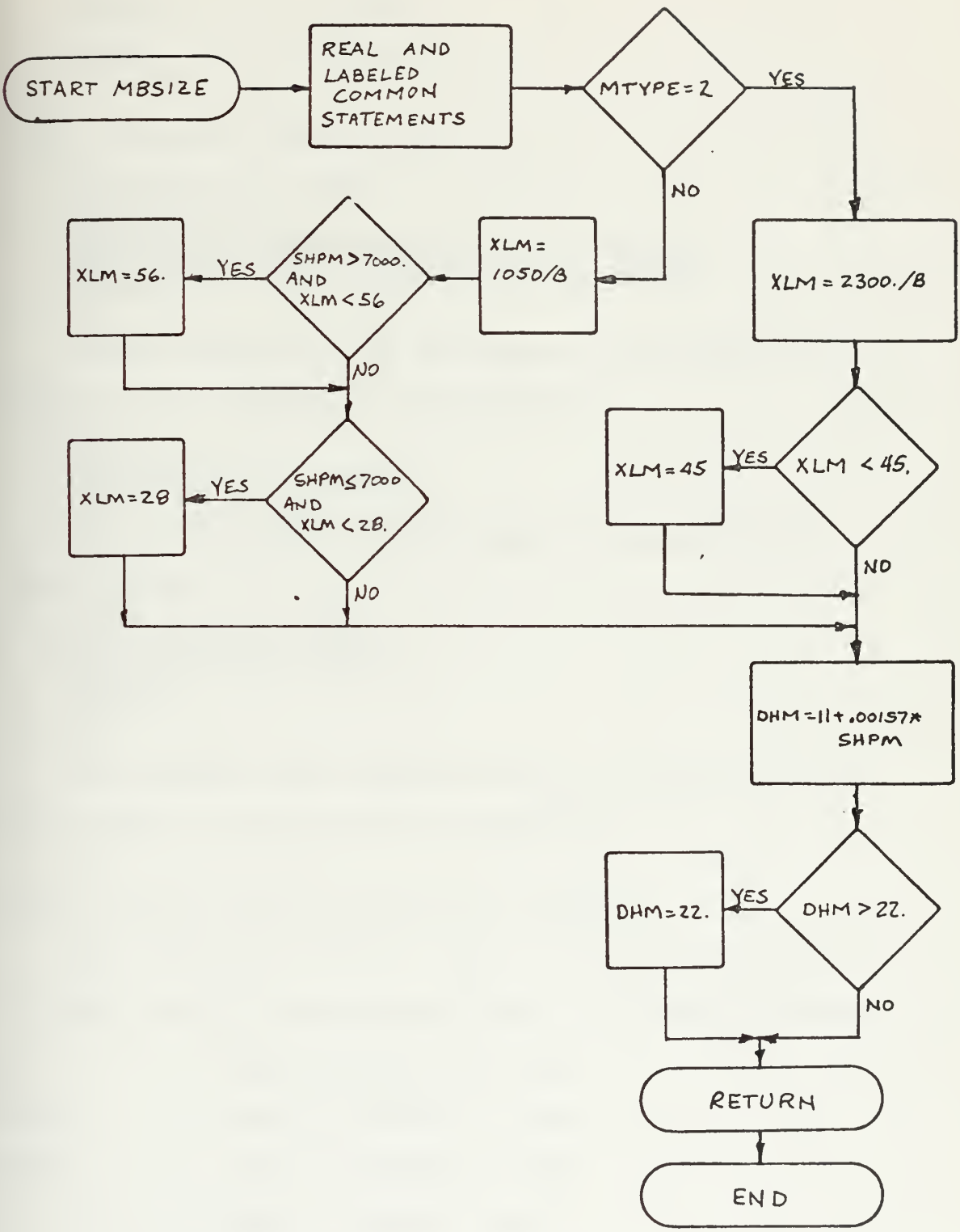



Figure 19

3.9.2 Input List for MBSIZE Subroutine

B.....SCDA

MTYPE.....LC(CC)

SHPM.....LC(CC)

3.9.3 Statement Descriptions

```
      IF(MTYPE.EQ.2) GOTO 1
      XLM=1050./B
      IF(SHPM.GT.7000..AND.XLM.LT.56.) XLM=56.
      IF(SHPM.LE.7000..AND.XLM.LT.28.) XLM=28.
      GOTO 2
```

These statements set the engine room length for diesel plants. (MTYPE = 1 for diesels)

```
    1 XLM=2300./B
      IF(XLM.LT.45.) XLM=45.
```

These statements set the engine room length for CODOG plants.

```
    2 DHM=11.+.00157*SHPM
      IF(DHM.GT.22.) DHM=22.
      RETURN
      END
```

The minimum deck height, which is the same for both plant types, is set by these statements.

3.9.4 Output List for Subroutine MBSIZE

All variables have the same definition as given in the MAIN program nomenclature except for the following:

| | |
|---|---|
| RE | same as RGEND in MAIN |
| SFCH | same as SFCHHP in MAIN |
| SFCM | same as SFCMHP in MAIN |
| VE | same as VEND in MAIN |

## 3.10 Subroutine VOLUME

### 3.10.1 Introduction

Many of the ships designed today are volume rather than weight limited. Because of this it is important that a ship synthesis model determine a balance between required and available volume as well as between weight and displacement. Subroutine VOLUME performs this function in the cutter model.

The dimensions of the hull below the load waterline are determined in subroutine UWDIM. Only the sheer line, deckhouse volume and the length of raised deck, if any, remain to be determined to define the volume available in the ship. The enclosed volume of the hull and deckhouse will be completely determined by these variables since the waterplane coefficient is calculated in subroutine UWDIM and since the general shape of the hull is implied by the estimating relationships used in the model.

Deckhouse volume is constrained primarily by stability considerations and by external deck area requirements. If the deckhouse becomes too high, it will not be possible to make the vessel stable. Also a certain amount of free deck area is required in nearly all designs, restricting the horizontal spreading of the deckhouse. At the other extreme, the ship may have excessive stability if too small a deckhouse is installed.

These deckhouse volume restrictions have been included

in the cutter model by restricting deckhouse size to be within the limits of past practice. Both an upper and a lower limit are placed on the size of the deckhouse as shown in Figure 20. The deckhouse volume of Coast Guard vessels has been generally greater than that of Navy designs. Upper and lower limits of $0.00150 \times L^3$ and $0.001 \times L^3$, respectively, are used in the Navy's destroyer model. This difference is probably due to the fact that the Navy requires more external deck area for armament.

The deckhouse volumes shown in Figure 20 do not include uptakes. It is assumed that sufficient additional area is available for uptakes since uptake area was excluded from the data points also. However, it is important to check a design be sketching a layout for the external decks and the superstructure before acceptance.

The volume in the hull is also estimated in VOLUME. The underwater volume is already available. The first step in determining the above water hull volume is the development of an acceptable sheer line. This step is performed by subroutine SHEER and is discussed in conjunction with that routine.

Once the sheer line and with it the average freeboard have been estimated, the above water volume is found by multiplying the area of the waterplane by the average freeboard and by a factor to account for flare. The total volume in the hull is the sum of the above and below water volumes.

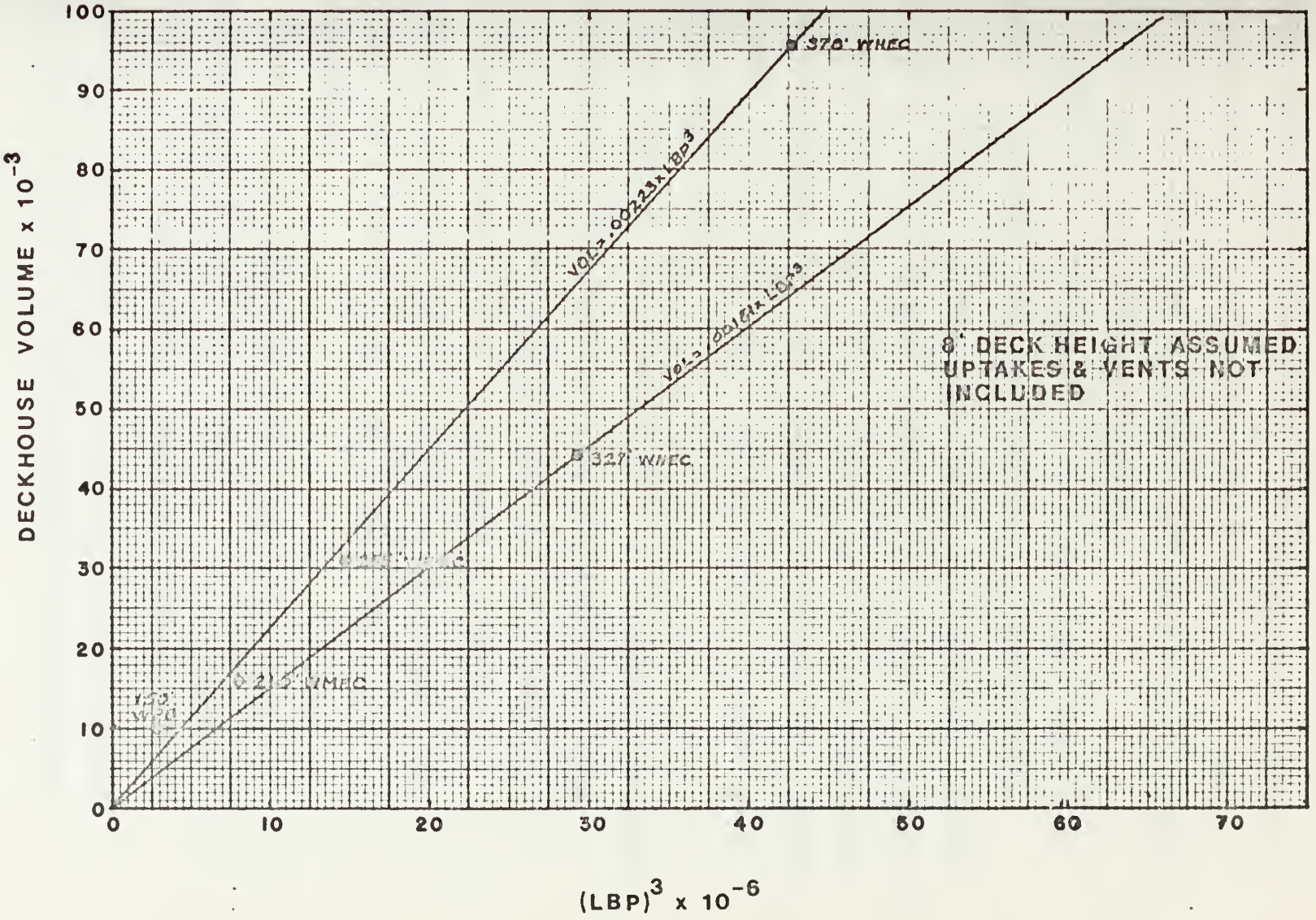

DECKHOUSE VOLUME x $10^{-3}$
$(LBP)^3$ x $10^{-6}$
0
10
20
30
40
50
60
70
80
90
100
0 370' WHEC
VOL = .00223 x LBP$^3$
VOL = .00123 x LBP$^3$
0 327' WHEC
8' DECK HEIGHT ASSUMED
UPTAKES & VENTS NOT
INCLUDED

Figure 20

This total hull volume includes the volume to the main deck only. The hull volume cannot be reduced below this size but a raised deck can be added to increase the volume of the hull. For vessels of the size of Coast Guard cutters it is impractical to add more than one raised deck. Also the deckhouse size can be varied somewhat to change the available volume.

Required hull volume is broken down into three categories. These are the machinery box, tankage volume and arrangements volume. The object of subroutine VOLUME is to alter the available volume so that there is sufficient space for each of the three categories of required volume. The model assumes that all tankage volume and the machinery box volume are in the hull. The deckhouse contains only arrangements volume.

The machinery box size is the first category estimated. This volume is found by multiplying the midships area by the length of the machinery box and by a machinery box prismatic coefficient. Machinery box volume is subtracted from the available hull volume to the main deck leaving a volume which can be used for tankage and arrangements.

Some of the remaining volume cannot be used for arrangements because of hull shape. The next step is to estimate the fraction of the remaining volume that can be used only for tankage. This is the minimum tankage volume for the ship. If less tankage is required for

the liquids that must be carried, the excess volume must be used for voids or cofferdams since it cannot be converted into machinery box space or arrangements volume. If more tankage is required than this minimum, some of the arrangements volume must be used for tankage.

The weights of all the liquids which must be carried are calculated in subroutine MACHLQ. In VOLUME, these weights are converted to volumes and added together. A twenty percent allowance is added to this figure to account for required cofferdams and voids. The volume required for liquids is then compared to the minimum tankage volume to determine the amount of arrangements volume, if any, that is required for tankage.

All of the volume remaining in the hull after tankage volume and machinery box volume have been subtracted, can be used for arrangements. The entire superstructure volume is also available for arrangements. Arrangements space requirements are more commonly given as areas rather than as volumes, so the next step is to convert the available arrangements volume to an available arrangements area. For the deckhouse this is a simple task since the deckhouse is nearly wall sided. The volume is divided by the deckheight of 8.5 feet to find the area. For the hull no such simple procedure is possible because of hull curvature.

The Navy performed extensive work on this problem while developing their destroyer model, DD07. This work

was made use of in the cutter model not only for the arrangements area formulation but also for the flare factor, machinery box prismatic coefficient and tankage volume fraction estimates discussed earlier. The relationships used in the cutter model were taken directly from the original notes[8] of Mr. Jim Mills who was largely responsible for the development work done by the Navy.

The major deviation between the cutter model and the destroyer model lies in the engine room location. The destroyer model assumes that the engine room is centered at amidships but Coast Guard practice usually places the engine room aft of amidships. No correction is made for this difference and the output produced for test runs with existing ships indicates that there is little effect.

By using the Navy's formula, the arrangements area in the hull can be calculated. This area plus the area of the deckhouse must be compared to the area required for all the ship's functions plus the area specified as input. The area required for ship's functions such as stores area, living area and auxiliary machinery area, are estimated in the cutter model based on past practice.

Data was obtained by measuring the areas of five past designs and assigning the areas to various categories. This data is summarized in Table 2. Linear relationships were developed from this data as shown in Figures 21 through 25. Berthing and sanitary areas are based on minimum Coast Guard standards. The area required for

| CATEGORY | 378 WHEC | 327 WHEC | 255 WHEC | 210 WMEC | 150 WPB |
|---|---|---|---|---|---|
| Office Spaces | 493 | 465 | 347 | 130 | 65 |
| Messing Facilities | 2713 | 2348 | 1379 | 1452 | 339 |
| Crew Special | 725 | 609 | 717 | 324 | 32 |
| Officer Staterooms | 1157 | 1338 | 966 | 567 | 187 |
| Officer Sanitary | 243 | 133 | 120 | 193 | 30 |
| CPO Staterooms | 1040 | 364 | 336 | 283 | 110 |
| CPO Sanitary | 250 | 100 | - | 75 | 27 |
| Crew Berthing | 3641 | 2655 | 2568 | 1658 | 375 |
| Crew Sanitary | 716 | 444 | 492 | 384 | 90 |
| CO Stateroom & Cabin | 697 | 511 | 273 | 406 | - |
| CO Pantry | 58 | 128 | 22 | - | - |
| Commissary Stores | 600 | 724 | 531 | 480 | 35 |
| Other Stores | 3015 | 2354 | 2397 | 1294 | 435 |
| Workshops | 1161 | 818 | 752 | 544 | - |
| Passages | 2567 | 2588 | 2138 | 739 | 229 |
| Repair Lockers | 148 | 18 | 97 | 110 | - |
| Steering Gear & Windlass | 736 | 548 | 645 | 270 | 294 |
| Chain Locker | 47 | 30 | 36 | 42 | 16 |
| A/C & Fan Spaces | 369 | 324 | 39 | 165 | - |
| I.C. & Gyro Room | 312 | 143 | 232 | 180 | - |
| Aux. Machinery Spaces | 1860 | 1874 | 414 | 820 | 543 |
| Uptakes (Hull) | 462 | 1216 | 64 | - | - |
| Pilothouse, Chartroom & C.I.C. | 1125 | 856 | 521 | 422 | 300 |
| Sub total | 24135 | 20588 | 15086 | 10538 | 3107 |
| EXTRAS | | | | | |
| Crew Recreation Rooms | 1445 | - | 682 | - | 71 |
| Cargo & Flume Tanks | 1219 | 249 | - | - | 241 |
| Electronics & Stores | 1618 | 775 | 1206 | 319 | 157 |
| Armament & Stores | 844 | 822 | 730 | 280 | - |
| Balloon Shelters | 512 | 156 | 120 | - | - |
| Mission Offices & Labs | 746 | 336 | 482 | - | - |
| Mission Workshops | - | - | 70 | 105 | - |
| Bow Thruster | 344 | - | - | - | - |
| Total | 30863 | 22926 | 18376 | 11242 | 3576 |

Table 2

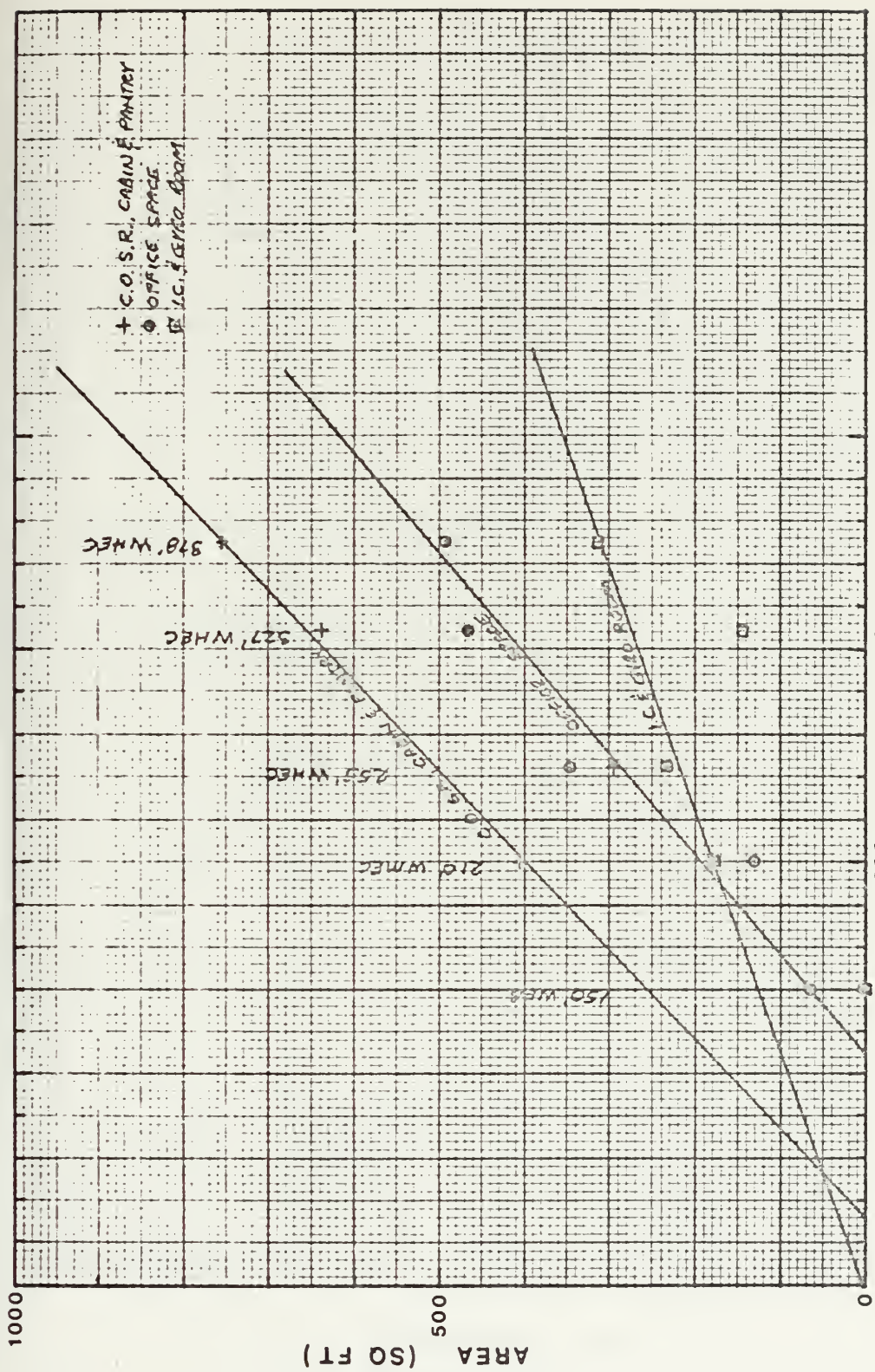

+ C.O. S.R., CABIN & PANTRY
● OFFICE SPACE
☐ LC. CARGO SPACE
318' WMEC
327' WHEC
253' WHEC
210' WMEC
150' WHEC
AREA (SQ FT)
1000
500
0
0
100
200
300
400
$L_{bp}$ (FT)

Figure 21

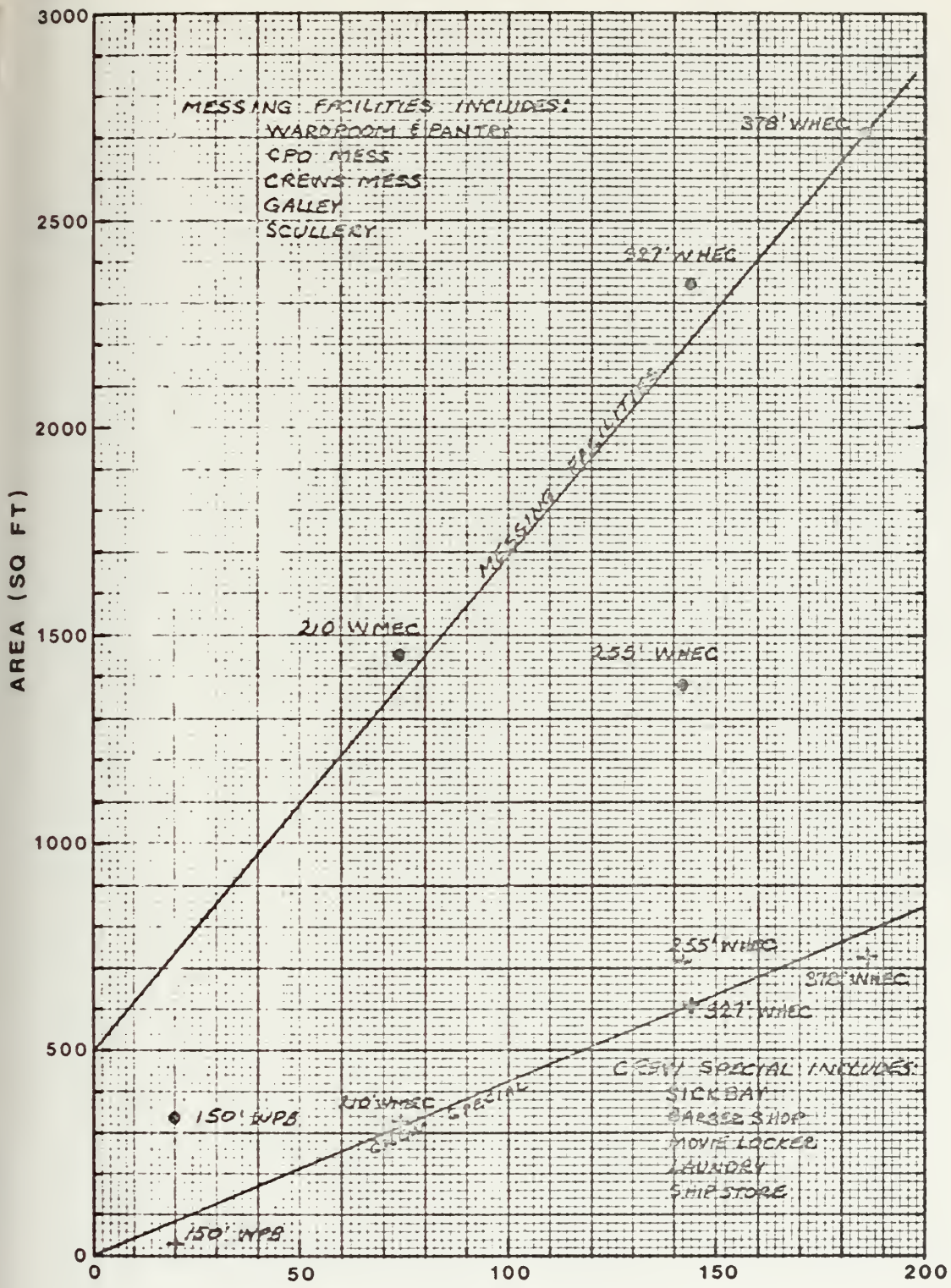

MESSING FACILITIES INCLUDES:
WARDROOM & PANTRY
CPO MESS
CREWS MESS
GALLEY
SCULLERY
378' WHEC
327' WHEC
210' WMEC
255' WHEC
255' WHEC
378' WHEC
327' WHEC
110' WPB
150' WPB
150' WPB
CREW SPECIAL INCLUDES:
SICK BAY
BARBER SHOP
MOVIE LOCKER
LAUNDRY
SHIP STORE
AREA (SQ FT)
No. of ACCOMMODATIONS
0
500
1000
1500
2000
2500
3000
0
50
100
150
200

Figure 22

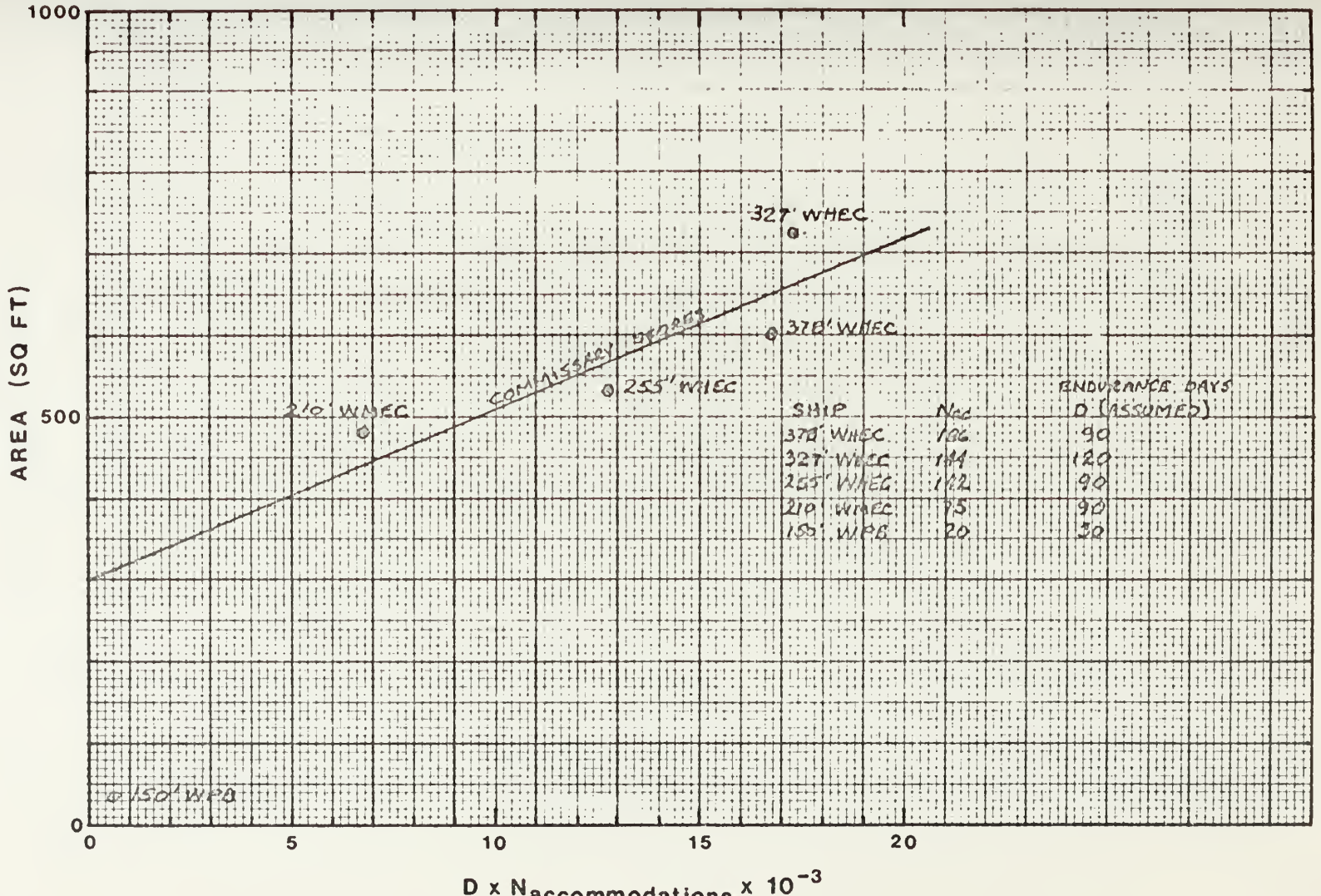

AREA (SQ FT)
1000
500
0
0
5
10
15
20
D x N accommodations x 10^-3
327' WHEC
378' WHEC
255' WHEC
210' WMEC
150' WPB
COMMISSARY EXPRESS
SHIP
N acc
ENDURANCE DAYS D (ASSUMED)
378' WHEC 166 90
327' WHEC 111 120
255' WHEC 112 90
210' WMEC 75 90
180' WPB 20 30

Figure 23

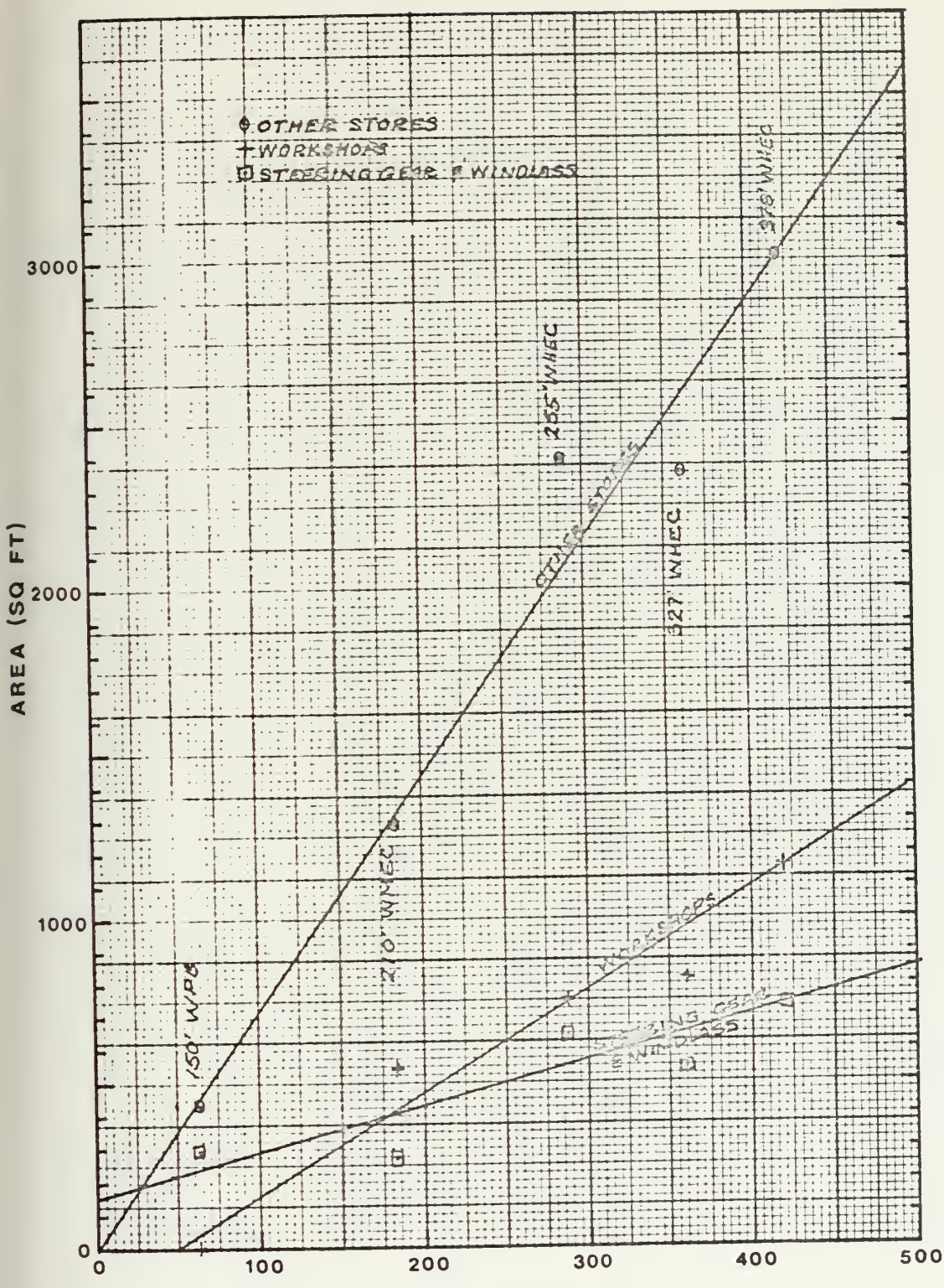

OTHER STORES
WORKSHOPS
STEERING GEAR & WINDLASS
375' WHEC
265' WHEC
327' WHEC
210' WHEC
150' WPB
OTHER STORES
WORKSHOPS
STEERING GEAR & WINDLASS
AREA (SQ FT)
0
1000
2000
3000
0
100
200
300
400
500
CUBIC NUMBER x $10^{-3}$

Figure 24

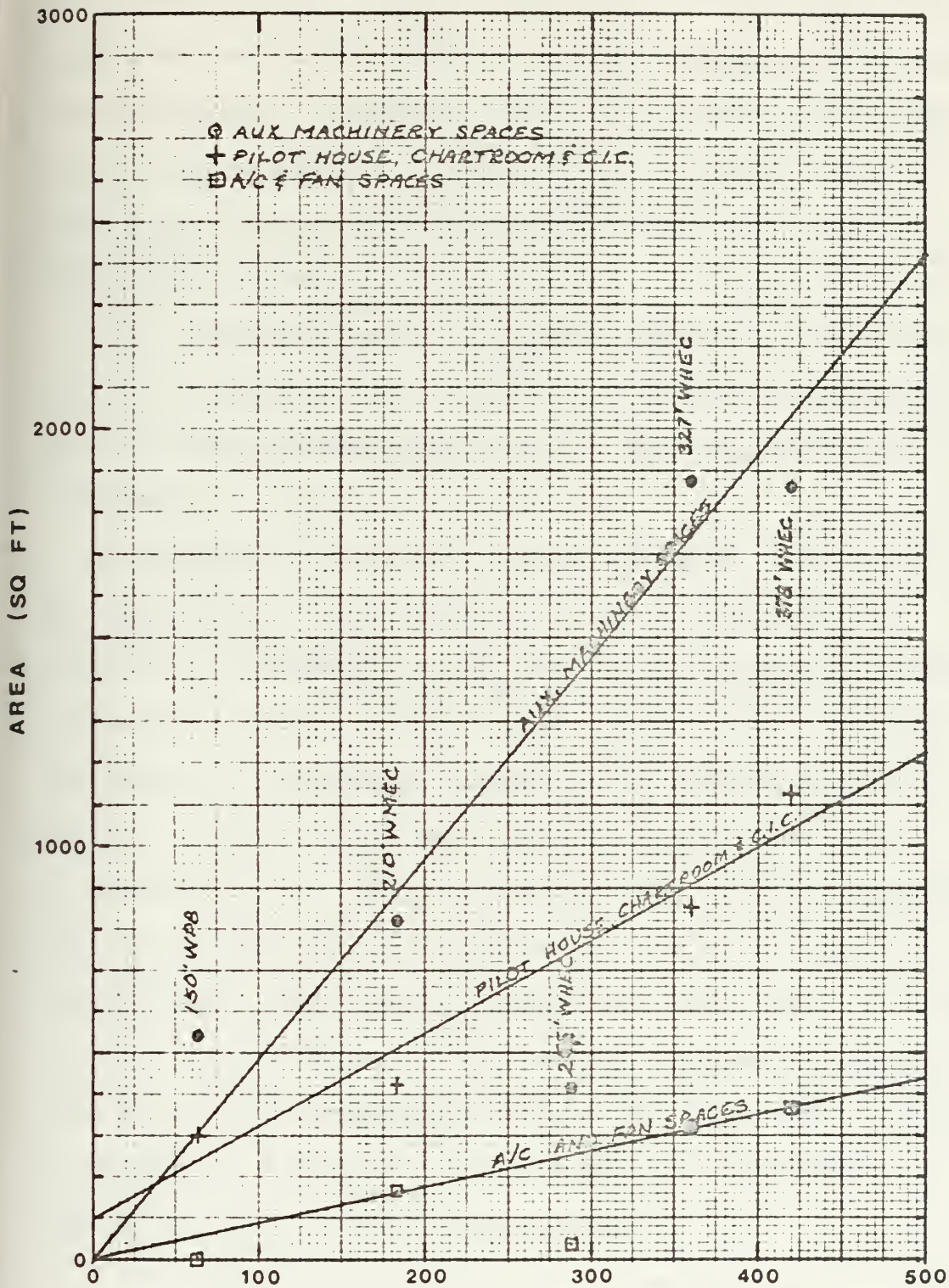

AUX MACHINERY SPACES
PILOT HOUSE, CHARTROOM & C.I.C.
A/C & FAN SPACES
AUX MACHINERY SPACES
PILOT HOUSE, CHARTROOM & C.I.C.
A/C AND FAN SPACES
150' WAB
210' WMEC
225' WHEC
327' WHEC
378' WHEC
AREA (SQ FT)
CUBIC NUMBER x $10^{-3}$
0
1000
2000
3000
0
100
200
300
400
500

Figure 25

repair lockers is taken as a constant 100 square feet. The area for chain lockers as 40 square feet and the area for uptakes in the hull as either 65 or 460 square feet depending on whether diesels or gas turbines, respectively, are installed. A constant value of nine percent of the total area is assumed for passages. Passages ranged from 6.84 to 13.17 percent of the total area on the five designs used.

All of the required areas are summed to determine the total required area. This area is then compared to the available arrangements area in the hull and superstructure.

Comparisons are made in the following order. First, the arrangements area required to be located in the deckhouse is compared to the area of the largest allowable deckhouse. If the required area exceeds that available, the design is infeasible and an error message must be printed. Next, the total required arrangements area is compared to the total available area. If the required area is the smaller, the deckhouse size is decreased. The deckhouse size used is either the size which balances the area requirements or the smallest allowable deckhouse size or the area required to be in the deckhouse, whichever is greatest. Should the total required area exceed that available a raised deck is added.

The length of raised deck is determined by an iterative procedure. On each iteration the area required to be

included in the raised deck is computed and the curve shown in Figure 26 is used to convert the area to a raised deck length. This curve is based on the main deck of a 378' WHEC. The iteration continues until two successive iterations fall within 5 percent of the length of the ship or until twenty iterations is reached. In the later case the design is ruled infeasible. A check is also made to insure that the raised deck length does-not exceed the length of the ship.

If the raised deck length lies between 0.4 and 0.6 times the length of the ship, the raised deck is extended to 0.6 times the length of the ship.

A flow chart for this routine is shown in Figures 27a and 27b.

3.10.2 Input List for Subroutine VOLUME

| | |
|---|---|
| AREADH.....LC(BB) | LEN.....LC(BB) |
| AREAHL.....LC(BB) | LMB.....LC(JJ) |
| B.....LC(GG) | MTYPE.....LC(CC) |
| CP.....LC(GG) | NCPO.....LC(AA) |
| CWP.....LC(GG) | NENL.....LC(AA) |
| CX.....LC(GG) | NOFF.....LC(AA) |
| D.....LC(AA) | WACFUL.....LC(LL) |
| DMB.....LC(JJ) | WTFUEL.....LC(LL) |
| H.....LC(GG) | WTLO.....LC(LL) |
| JOPT.....LC(CC) | WTPS.....LC(LL) |

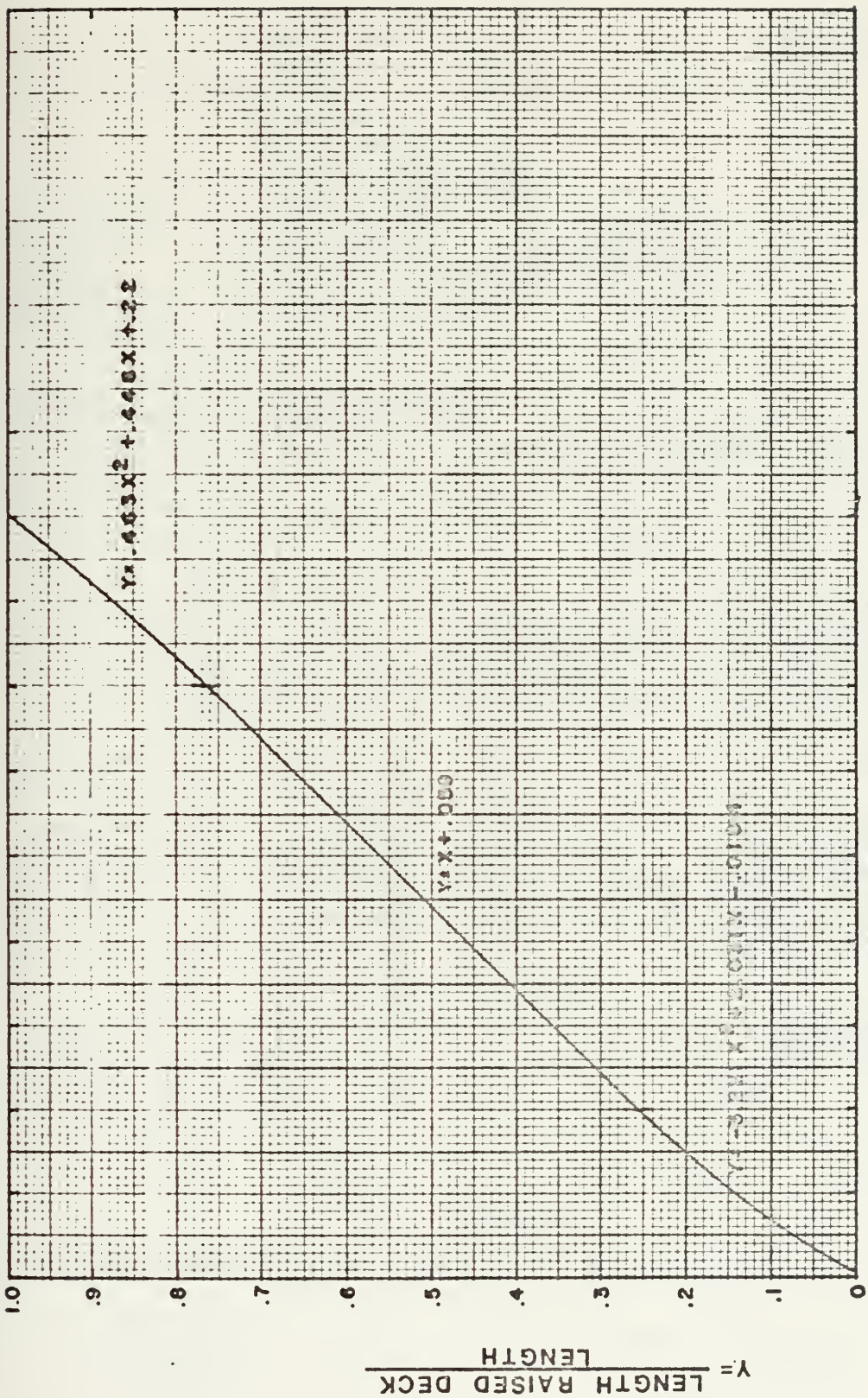

Y= -.403X² + .448X + .22
Y = X + .000
Y= LENGTH RAISED DECK / LENGTH
X = RAISED DECK AREA / BEAM x LENGTH
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0

Figure 26

# VOLUME SUBROUTINE FLOW CHART

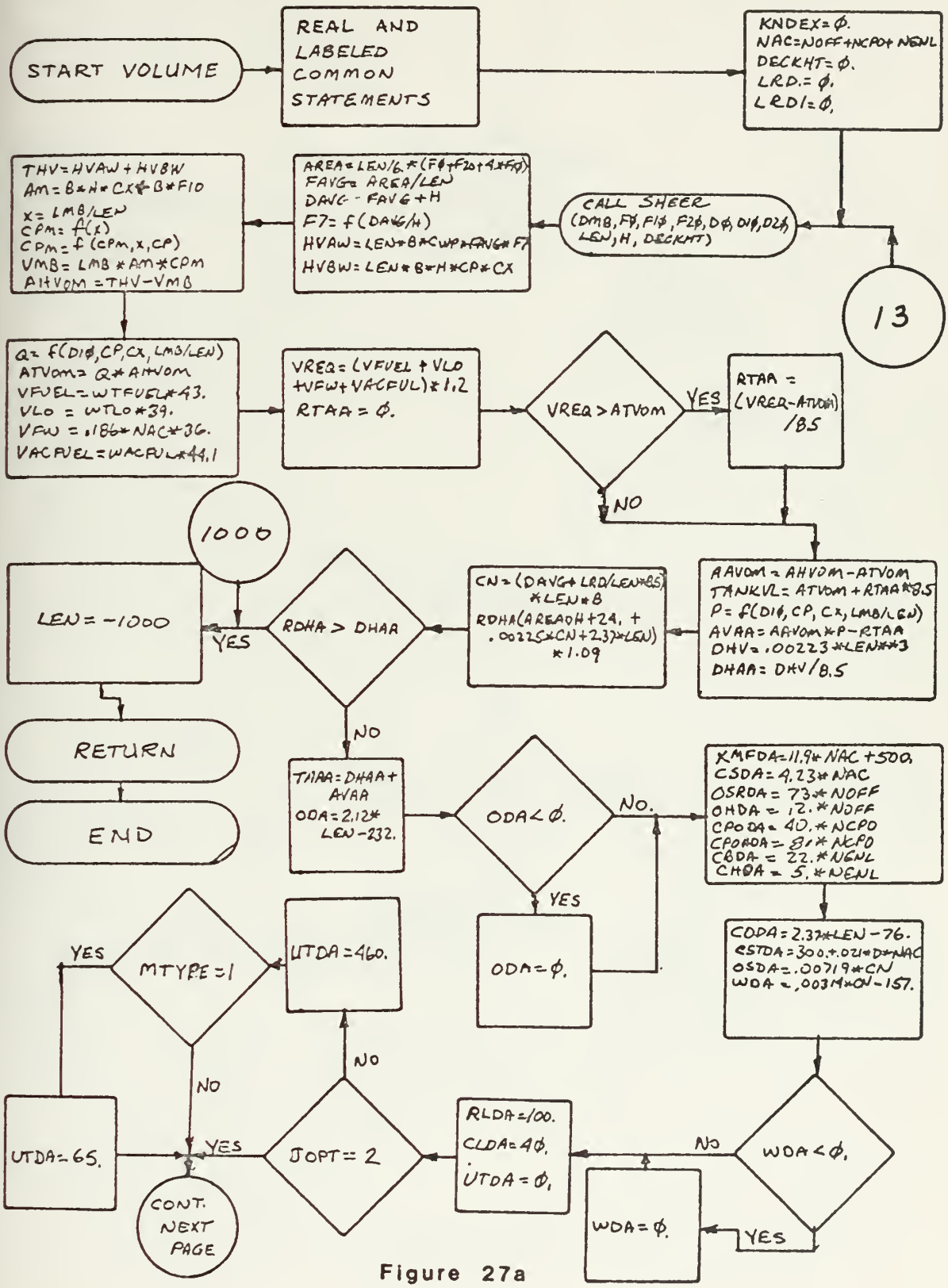



Figure 27a

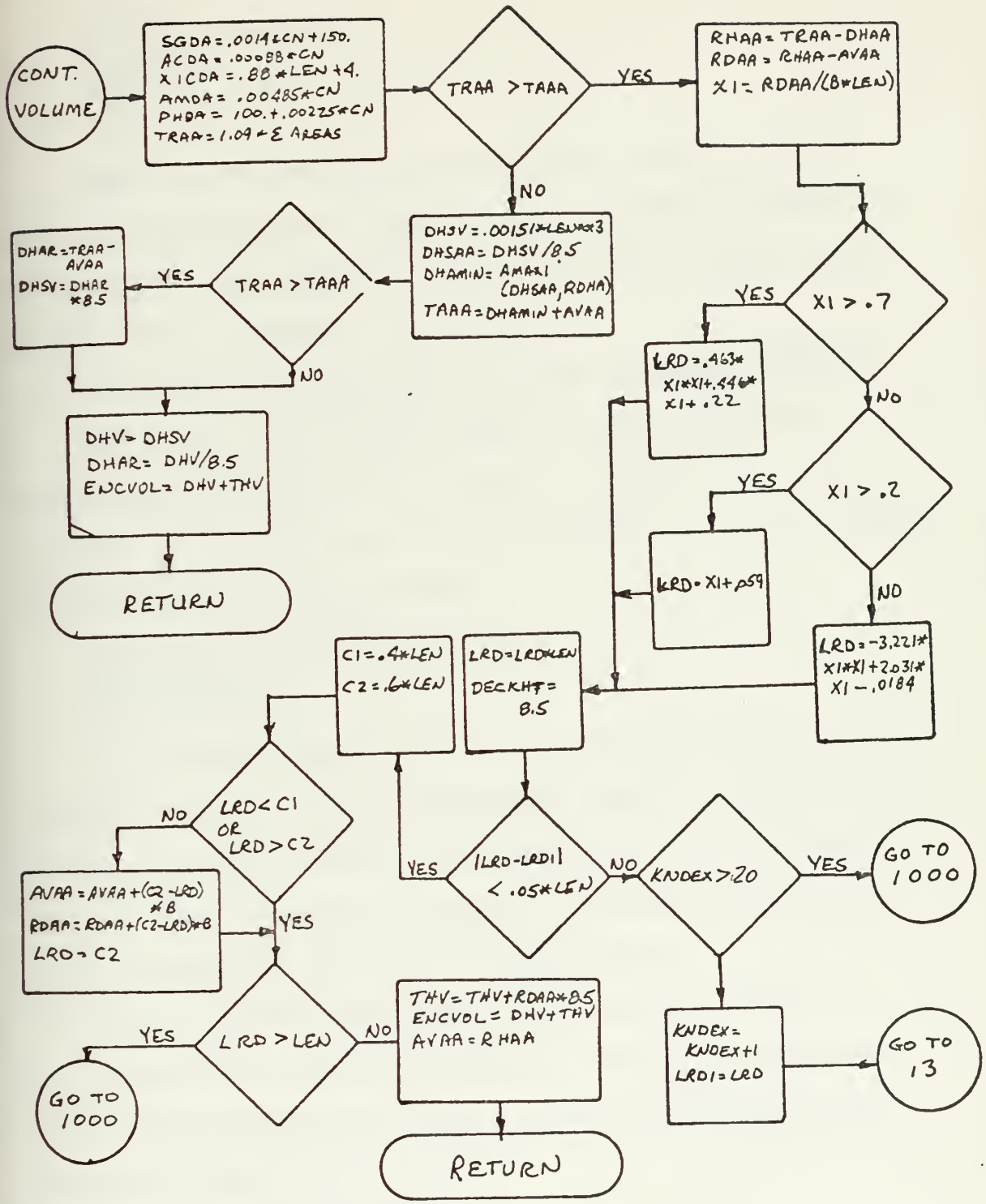

CONT. VOLUME
SGDA=.0014*CN+150.
ACDA=.00098*CN
XICDA=.88*LEN+4.
AMDA=.00485*CN
PHDA=100.+.00225*CN
TRAA=1.09*Σ AREAS
TRAA >TAAA
YES
NO
RHAA=TRAA-DHAA
RDAA=RHAA-AVAA
X1=RDAA/(B*LEN)
DHSV=.0015I*LEN**3
DHSAA=DHSV/8.5
DHAMIN=AMAX1 (DHSAA,RDHA)
TAAA=DHAMIN+AVAA
TRAA > TAAA
YES
NO
DHAR=TRAA-AVAA
DHSV=DHAR*8.5
X1 > .7
YES
NO
LRD=.463*X1**X1+.446*X1+.22
X1 > .2
YES
NO
LRD=X1+.59
LRD=-3.221*X1**X1+2.031*X1-.0184
DHV=DHSV
DHAR=DHV/8.5
ENCVOL=DHV+THV
RETURN
C1=.4*LEN
C2=.6*LEN
LRD=LRD*LEN
DECKHT=8.5
LRD<C1 OR LRD>C2
NO
YES
AVAA=AVAA+(C2-LRD)*B
RDAA=RDAA+(C2-LRD)*B
LRD=C2
|LRD-LRD1| < .05*LEN
YES
NO
KNDEX>20
YES
GO TO 1000
KNDEX=KNDEX+1
LRD1=LRD
GO TO 13
LRD > LEN
YES
NO
GO TO 1000
THV=THV+RDAA*8.5
ENCVOL=DHV+THV
AVAA=RHAA
RETURN

Figure 27b

3.10.3 Statement Descriptions

```
KNDEX=0
NAC=NOFF+NCPO+NENL
DECKHT=0.
LRD=0.
LRD1=0.
```

KNDEX is an iteration counter used for the raised deck length iteration. The variable DECKHT is explained in the SHEER subroutine. The two values of raised deck length start at zero.

```
13 CALL SHEER(DMB,F0,F10,F20,D0,D10,D20,LEN,H,DECKHT)
```

The sheer line of the vessel is defined by the freeboard at stations 0, 10, and 20. These values are returned as F0, F10, and F20 respectively. The associated hull depths are also returned.

```
AREA=LEN/6.*(F0+F20+4*F10)
FAVG=AREA/LEN
DAVG=FAVG+H
```

The average depth is calculated using the projected lateral area. A better estimation could be made by using the local beam to weight the freeboard values but this was not done.because the value of F7 which corrects for flare is based on the above average depth.

```
F7=-.018828*(DAVG/H)**2+.18098*DAVG/H+.714599
```

This is the flare correction factor. The formula used was taken from the Navy's work in developing their destroyer model.

```
HVAW=LEN*B*CWP*FAVG*F7
HVBW=LEN*B*H*CP*CX
THV=HVAW+HVBW
```

The total hull volume to the main deck is calculated

by these statements.

```
AM=B*H*CX+B*F10
X=LMB/LEN
CPM=-.525*X*X+.055*X+.99675
CPM=CPM+3.2*X*X*(CP-.6)
VMB=LMB*AM*CPM
AHVOM=THV-VMB
```

The volume of the machinery box and the remaining available hull volume are calculated in these statements. The formula for CPM has been taken from the Navy's work and applies to machinery boxes centered about amidships.

```
Q=(-.9037115+.2139727*D10-1.38263E-2*D10**2+
     4.008058E-4*D10**3-5.489481E-6*D10**4+
     2.892153E-8*D10**5)*CP/.58*CX/.814*
     (1.11*LMB/LEN+.667)
ATVOM=Q*AHVOM
VFUEL=WTFUEL*43.
VLO=WTLO*39.
VFW=.186*NAC*36.
VACFUL=WACFUL*44.1
VREQ=(VFUEL+VLO+VFW+VACFUL)*1.2
RTAA=0.
IF(VREQ.GT.ATVOM) RTAA=(VREQ-ATVOM)/8.5
AAVOM=AHVOM-ATVOM
TANKVL=ATVOM+RTAA*8.5
```

The available volume which can be used only for tankage and the required tankage volume are calculated and compared in these statements. The formula for Q was again taken from the destroyer model work. The required tankage arrangements area is calculated if the required tankage volume is in excess of that available.

```
P=(6.51041E-7*D10**3-7.851484E-5*D10**2+3.438375E-3*
     D10+.0530399)*(.191*CP+.8893)*(.191*CX+.8445)*
     (-.105*LMB/LEN+1.0315)
AVAA=AAVOM*P-RTAA
```

The available arrangements volume is converted to an available arrangements area again using a Navy developed formula.

```
      DHV=.00223*LEN**3
      DHAA=DHV/8.5
      CN=(DAVG+LRD/LEN*8.5)*LEN*B
      RDHA=(AREADH+24.+.00225*CN+2.37*LEN)*1.09
      IF(RDHA.GT.DHAA) GOTO 1000
      TAAA=DHAA+AVAA
```

The area in the largest acceptable deckhouse is compared to the area required to be in the deckhouse.' If the required area is smaller, the program continues. If not, an error message is printed. The areas required to be in the deckhouse include the input areas plus the commanding officers cabin and the pilothouse. An allowance is also made for passageways.

```
      ODA=2.12*LEN-232.
            .
            .
            .
      PHDA=100.+.00225*CN
```

The statements above and those included between them are used to calculate the required deck areas.

```
      TRAA=1.09*(AREADH+AREAHL+ODA+XMFDA+CSDA+OSRDA+OHDA+
           CPODA+CPOHDA+CBDA+CHDA+CODA+CSTDA+CSDA+WDA+
           RLDA+CLDA+UTDA+SGDA+ACDA+XICDA+AMDA+PHDA)
      IF(TRAA.GT.TAAA) GOTO 10
```

The total required arrangements area is computed and compared with the area available in the hull to the main deck plus the largest acceptable deckhouse. A decision is then made to either make the deckhouse smaller or to add a raised deck.

```
      DHSV=.00151*LEN**3
      DHSAA=DHSV/8.5
      DHAMIN=AMAX1(DHSAA,RDHA)
      TAAA=DHAMIN+AVAA
      IF(TRAA.GT.TAAA) GOTO 11
   12 DHV=DHSV
      DHAA=DHV/8.5
```

```
    ENCVOL=DHV+THV
    RETURN
 11 DHAR=TRAA-AVAA
    DHSV=DHAR*8.5
    GOTO 12
```

These statements compute the deckhouse size required if the deckhouse is to be made smaller. First, the larger value of the minimum deckhouse size or the required deckhouse area is chosen and added to the hull voulume. This new available area is then compared to the total required area. If the available area is still the greater, the difference is excess area that cannot be reduced since the minimum size hull and deckhouse are already being used. If more than the minimum deckhouse size is required a calculation is made to balance the total required area and the total available area.

```
 10 RHAA=TRAA-DHAA
    RDAA=RHAA-AVAA
    X1=RDAA/(B*LEN)
    IF(X1.GT..7) GOTO 1
    IF(X1.GT..2) GOTO 2
    LRD=-3.22*X1*X1+2.031*X1-.0184
    GOTO 3
  1 LRD=.463*X1*X1+.446*X1+.22
    GOTO 3
  2 LRD=X1+.059
  3 LRD=LRD*LEN
    DECKHT=8.5
    IF(ABS(LRD-LRD1).LT..05*LEN) GOTO 15
    IF(KNDEX.GT.20) GOTO 1000
    KNDEX=KNDEX+1
    LRD1=LRD
    GOTO 13
```

If more area is required than is available in the largest deckhouse plus the hull to the main deck, a raised deck is added. The assumption is made that a ship with the maximum deckhouse size will result in the least

displacement. This is probably valid so long as an aluminum deckhouse is used.

The length of raised deck required is computed in the above statements. The new raised deck length is then compared to the former estimate, LRD1. If the two do not agree within five percent of the length of the ship a new iteration is made. A default counter has been included to keep the computer from being caught in a nonconverging loop.

```
 15 C1=.4*LEN
    C2=.6*LEN
    IF(LRD.LT.C1.OR.LRD.GT.C2) GOTO 4
    AVAA=AVAA+(C2-LRD)*B
    RDAA=RDAA+(C2-LRD)*B
    LRD=C2
```

These statements check to see if the raised deck length falls within 0.4 to 0.6 times the ship length. If so the calculated values are corrected so that the raised deck length is equal to 0.6 times the ship length.

```
  4 IF(LRD.GT.LEN) GOTO 1000
    THV=THV+RDAA*8.5
    ENCVOL=DHV+THV
    RETURN
```

A check is first made to insure that a raised deck length longer than the length of the ship is not required. A corrected total volume is then calculated and the program returns.

```
1000 LEN=-1000.
     RETURN
     END
```

Statement 1000 is a default option warning subroutine XECUTE to print an error message.

3.10.4 Output List for Subroutine VOLUME

| | |
|---|---|
| ACDA.....LC(PP) | DHV.....LC(BB) |
| AMDA.....LC(PP) | ENCVOL.....LC(BB) |
| AVAA.....LC(PP) | LRD.....LC(JJ) |
| CBDA.....LC(PP) | ODA.....LC(PP) |
| CHDA.....LC(PP) | OHDA.....LC(PP) |
| CLDA.....LC(PP) | OSDA.....LC(PP) |
| CN.....LC(BB) | OSRDA.....LC(PP) |
| CODA.....LC(PP) | PHDA.....LC(PP) |
| CPODA.....LC(PP) | RLDA.....LC(PP) |
| CPOHDA.....LC(PP) | SGDA.....LC(PP) |
| CSDA.....LC(PP) | TANKVL.....LC(PP) |
| CSTDA.....LC(PP) | UTDA.....LC(PP) |
| D0.....LC(II) | VMB.....LC(PP) |
| D10.....LC(II) | WDA.....LC(PP) |
| D20.....LC(II) | XICDA.....LC(PP) |
| DAVG.....LC(BB) | XMFDA.....LC(PP) |
| DHAA.....LC(PP) | |

3.10.5 Nomenclature List

The definition of all variables is the same as given in the MAIN program nomenclature except for the following:

| | |
|---|---|
| AAVOM | available arrangements volume in hull, cu ft |
| ACDA | A/C & ventilation deck area, sq ft |
| AHVOM | available hull volume, cu ft |
| AM | cross sectional area amidships, sq ft |
| AMDA | aux. machinery spaces deck area, sq ft |
| AREA | projected lateral area above water, sq ft |

| | |
|---|---|
| ATVOM | available tankage volume, cu ft |
| AVAA | available arrangements area in hull, sq ft |
| C1 | 0.4 x length, ft |
| C2 | 0.6 x length, ft |
| CBDA | crews berthing deck area, sq ft |
| CHDA | crews heads deck area, sq ft |
| CLDA | chain locker deck area, sq ft |
| CODA | C.O. S.R., Cabin & pantry deck area, sq ft |
| CPM | machinery box prismatic coefficient |
| CPODA | CPO S.R. deck area, sq ft |
| CPOHDA | CPO heads deck area, sq ft |
| CSDA | crew special deck area, sq ft |
| CSTDA | commissary stores deck area, sq ft |
| D | same as ENDDAY in MAIN |
| D0 | depth at F.P., ft |
| D10 | depth at amidships, ft |
| D20 | depth at A.P., ft |
| DECKHT | height of raised deck, ft |
| DHAA | deckhouse arrangements area, sq ft |
| DHAMIN | minimum deckhouse area, sq ft |
| DHAR | deckhouse area required, sq ft |
| DHSAA | smallest deckhouse arrangements area, sq ft |
| DHSV | smallest deckhouse volume, cu ft |
| DMB | same as DHM in MAIN |
| F0 | freeboard at F.P., ft |
| F7 | flare factor |
| F10 | freeboard at amidships, ft |

| | |
|---|---|
| F20 | freeboard at A.P.,ft |
| FAVG | average freeboard, ft |
| HVAW | hull volume above waterline, cu ft |
| HVBW | hull volume below waterline, cu ft |
| KNDEX | counter |
| LMB | same as XLM in MAIN |
| LRD1 | used to store LRD value |
| NAC | number of accommodations. |
| ODA | office deck area, sq ft |
| OHDA | officer heads deck area, sq ft |
| OSDA | other stores deck area, sq ft |
| OSRDA | officer staterooms deck area, sq ft |
| P | coefficient |
| PHDA | pilothouse, chartroom & CIC deck area, sq ft |
| Q | coefficient |
| RDAA | raised deck arrangements area, sq ft |
| RDHA | area required to be in deckhouse, sq ft |
| RE | same as RGEND in MAIN |
| RHAA | required hull arrangements area, sq ft |
| RLDA | repair locker deck area, sq ft |
| RTAA | required tankage arrangements area, sq ft |
| SFCH | same as SFCHHP in MAIN |
| SFCM | same as SFCMHP in MAIN |
| SGDA | steering gear & windlass deck area, sq ft |
| TAAA | total available arrangements area, sq ft |
| TANKVL | tankage volume, cu ft |

| | |
|---|---|
| THV | total hull volume, cu ft |
| TRAA | total required arrangements area, sq ft |
| UTDA | uptake deck area in hull, sq ft |
| VACFUL | volume of aircraft fuel, cu ft |
| VE | same as VEND in MAIN |
| VFUEL | volume of ships fuel, cu ft |
| VFW | volume potable water, cu ft |
| VLO | volume of lub oil, cu ft |
| VMB | volume of machinery box, cu ft |
| VREQ | required tankage volume, cu ft |
| WDA | workshops deck area, sq ft |
| X | LMB/LEN |
| X1 | RDAA/(B*LEN) |
| XICDA | I.C. & gyro room deck area, sq ft |
| XMFDA | messing facilities deck area, sq ft |

## 3.11 Subroutine SHEER

### 3.11.1 Introduction

Subroutine SHEER selects an appropriate sheer line by specifying the freeboard at the forward perpendicular, amidships, and at the after perpendicular. This sheer line must satisfy a number of criteria.

First, there must be sufficient depth amidships to accommodate the engine room. The depth amidships must also be sufficient to insure adequate structural strength. A minimum value of L/16 is used. Because Coast Guard vessels normally have engine rooms aft of amidships, a slightly greater depth amidships is used rather than the machinery box depth. This accounts for the drop in the sheer line aft of amidships.

The next criterion which must be satisfied is adequate freeboard at the forward and after perpendiculars. Navy derived formulas were used. These formulas give the minimum acceptable freeboard based on a deck wetness criterion.

Once independent determinations of freeboard at the forward and after perpendiculars and at amidships are made, a check is required to insure that a reasonable sheer line can be drawn between the three. Data was obtained from past designs and from the standard merchant ship sheer curves. This data was nondimensionalized by subtracting the freeboard amidships from the other freeboard values and then dividing by the length of the ship.

The resulting curves are plotted in Figure 28.

The sheer line is assumed to be practical if the forward sheer fraction lies between 0.01 and 0.03 and the after sheer fraction lies between 0.001 and 0.0075. If this is not the case, one or more of the freeboard values is adjusted until the criterion is satisfied.

If a raised deck is added to the hull, a new sheer line is calculated. It is assumed that the required freeboard of the main deck at the forward perpendicular can be one deck height or 8.5 feet below that required by the deck wetness criterion. This will result in a flattened sheer line as is common for raised deck vessels.

A flow chart for this routine is shown in Figure 29.

3.11.2 Input List for Subroutine SHEER

| | |
|---|---|
| DMB.....SCDA | H.....SCDA |
| LEN.....SCDA | DECKHT.....SCDA |

3.11.3 Statement Descriptions

```
D10=.0025*LEN+DMB
IF(D10.LT.LEN/16) D10=LEN/16.
```

The minimum depth amidships is selected by these statements.

```
F0=1.011827*(100.*H/LEN)-.000636215*LEN+2.780649
F0=LEN*F0/100.
F0=F0-DECKHT
D0=F0+H
```

The minimum depth at the forward perpendicular is selected here.

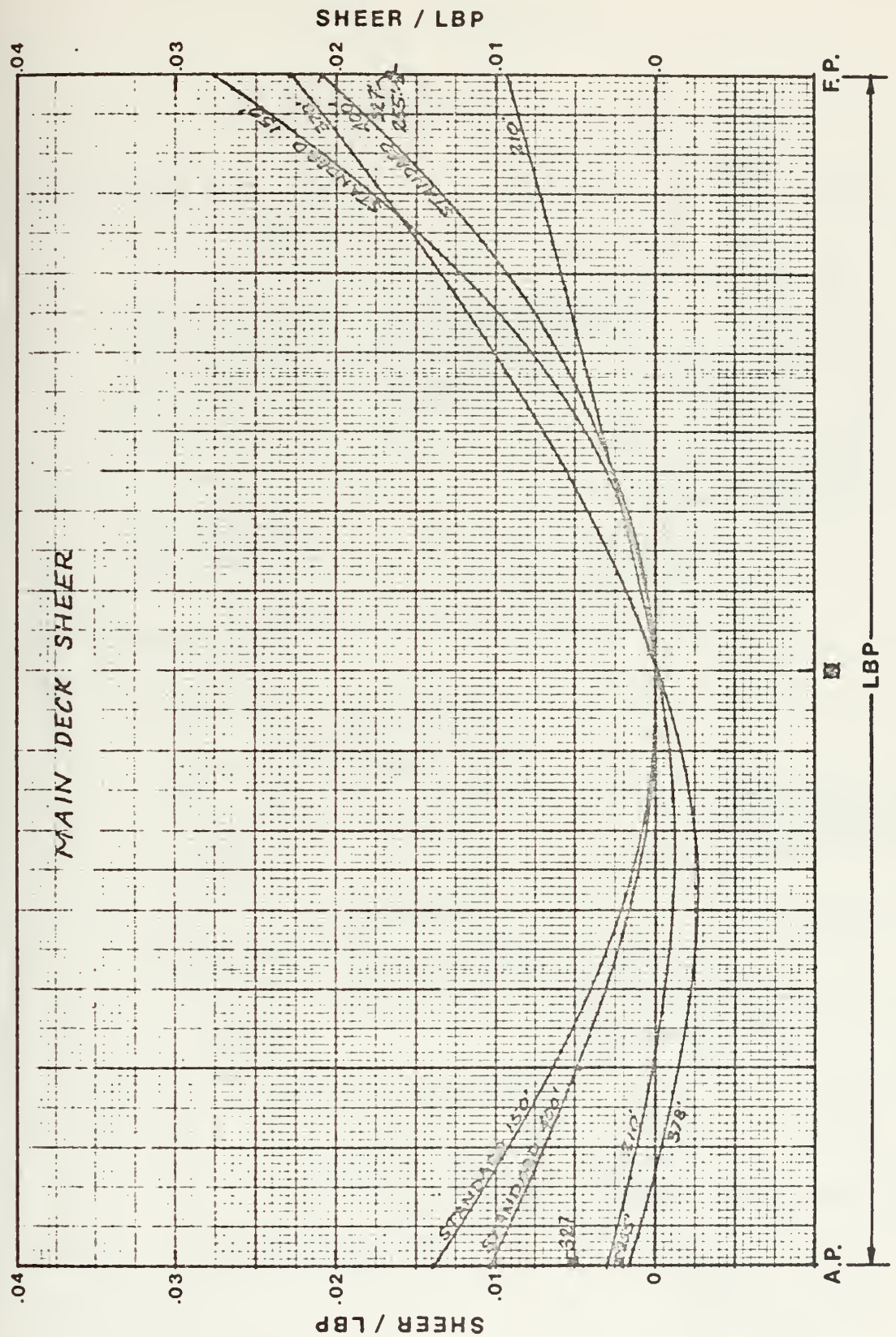

SHEER / LBP
.04
.03
.02
.01
0
F.P.
MAIN DECK SHEER
210'
327'
255'
150'
327'
210'
378'
A.P.
LBP
SHEER / LBP

Figure 28

# SHEER SUBROUTINE FLOW CHART

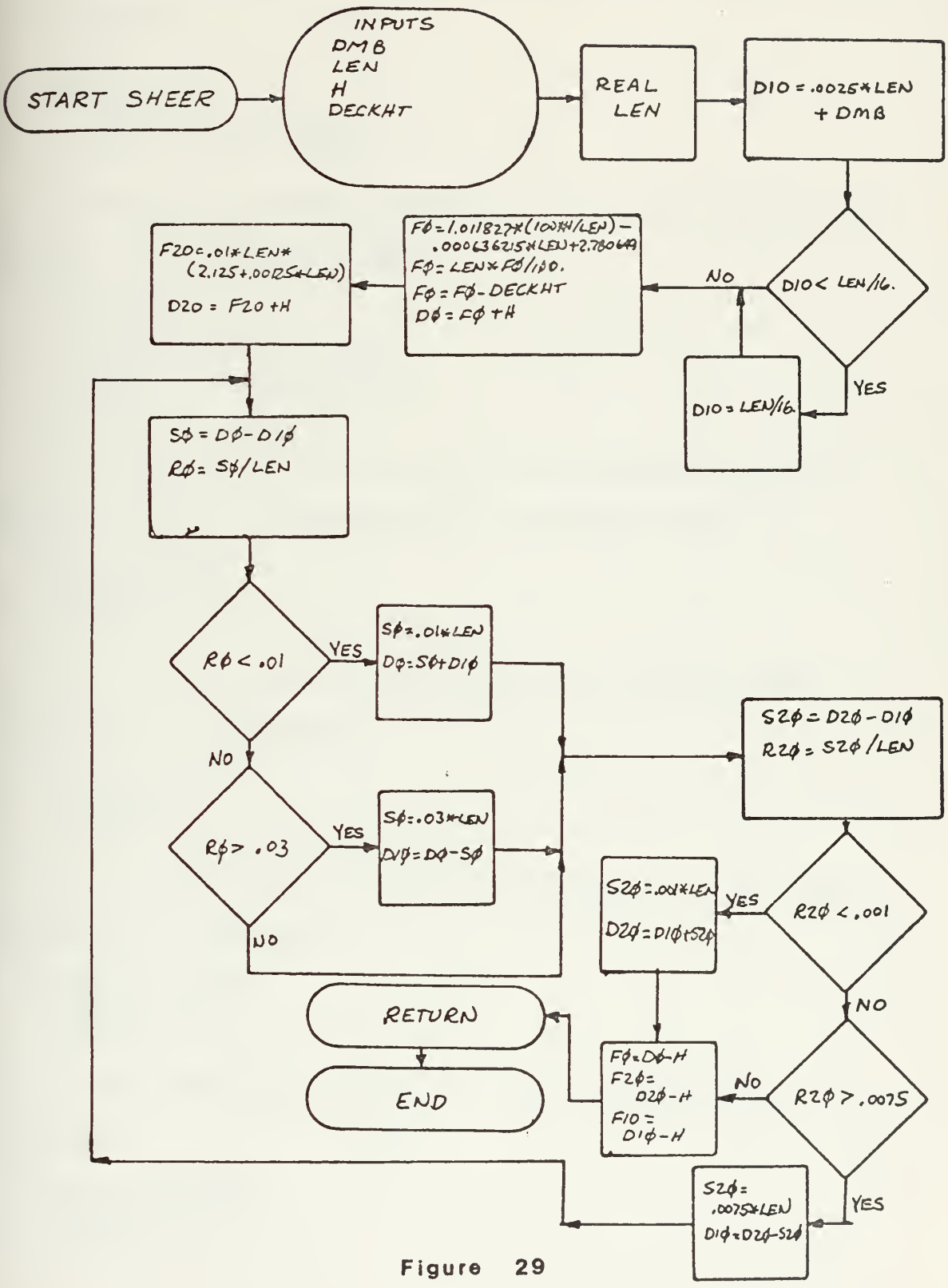



Figure 29

```
      F20=.01*LEN*(2.125+.00125*LEN)
      D20=F20+H
```

Finally the minimum depth at the after perpendicular is selected.

```
    7 S0=D0-D10
      R0=S0/LEN
      IF(R0.LT..01) GOTO 1
      IF(R0.GT..03) GOTO 2
```

The sheer fraction forward is calculated and checked against the acceptable limits.

```
    6 S20=D20-D10
      R20=S20/LEN
      IF(R20.LT..001) GOTO 3
      IF(R20.GT..0075) GOTO 4
      GOTO 5
```

The sheer fraction at the after perpendicular is calculated and checked against acceptable limits.

```
    1 S0=.01*LEN
      D0=S0+D10
      GOTO 6
```

If the freeboard at the bow is too low the depth at the bow is increased.

```
    2 S0=.03*LEN
      D10=D0-S0
      GOTO 6
```

If the freeboard at the bow is excessive, the depth amidships is increased.

```
    3 S20=.001*LEN
      D20=D10+S20
      GOTO 5
```

If the freeboard aft is too low the depth aft is increased.

```
    4 S20=.0075*LEN
      D10=D20-S20
      GOTO 7
```

If the freeboard aft is excessive the depth amidships is increased and the sheer fraction at the bow is rechecked.

```
5 F0=D0-H
  F20=D20-H
  F10=D10-H
  RETURN
  END
```

Values of both freeboard and depth are returned for use in subroutine volume.

3.11.4 Output List for Subroutine SHEER

| | |
|---|---|
| F0.....SCDA | D0.....SCDA |
| F10.....SCDA | D10.....SCDA |
| F20.....SCDA | D20.....SCDA |

3.11.5 Nomenclature List

| | |
|---|---|
| D0 | depth at forward perpendicular, ft |
| D10 | depth at amidships, ft |
| D20 | depth at after perpendicular, ft |
| DECKHT | height of raised deck, ft |
| DMB | machinery box depth, ft |
| F0 | freeboard at bow, ft |
| F10 | freeboard amidships, ft |
| F20 | freeboard at stern, ft |
| H | draft, ft |
| LEN | length between perpendiculars, ft |
| R0 | (D0-D10)/LEN |
| R20 | (D20-D10)/LEN |
| S0 | D0-D10 |
| S20 | D20-D10 |

## 3.12 Subroutine WEIGHT

### 3.12.1 Introduction

Subroutine VOLUME balanced the required and available volumes in the hull. This subroutine estimates weights so that a balance can be made between full load weight and displacement.

Several of the weights required have already been calculated or were given as input. Calculated weights include the fuel weight and lub oil weight. All communications and control, group 4, weights and all armament, group 7, weights are given as input. The weight groups noted refer to the NAVSHIPS Hull Group Weight Classification of 1965. The categories in this classification scheme are given in Appendix E. This is the classification system now used by the Coast Guard.

Also given as input are the weights of cargo, aircraft, ammunition and aircraft fuel. All other weights which are a part of the full load weight are estimated in subroutine WEIGHT. A flow chart for this routine is shown in Figure 30.

There are few patrol cutters of recent vintage which can be used for collecting weight data. Three have been used throughout this model. These are the 378' WHEC, the 210' WHEC, and the 150' WPB. Wherever possible additional data has been shown. Light ship weight data was taken from the weight breakdown sheets prepared for each design. Load weights were taken from

# WEIGHT SUBROUTINE FLOW CHART

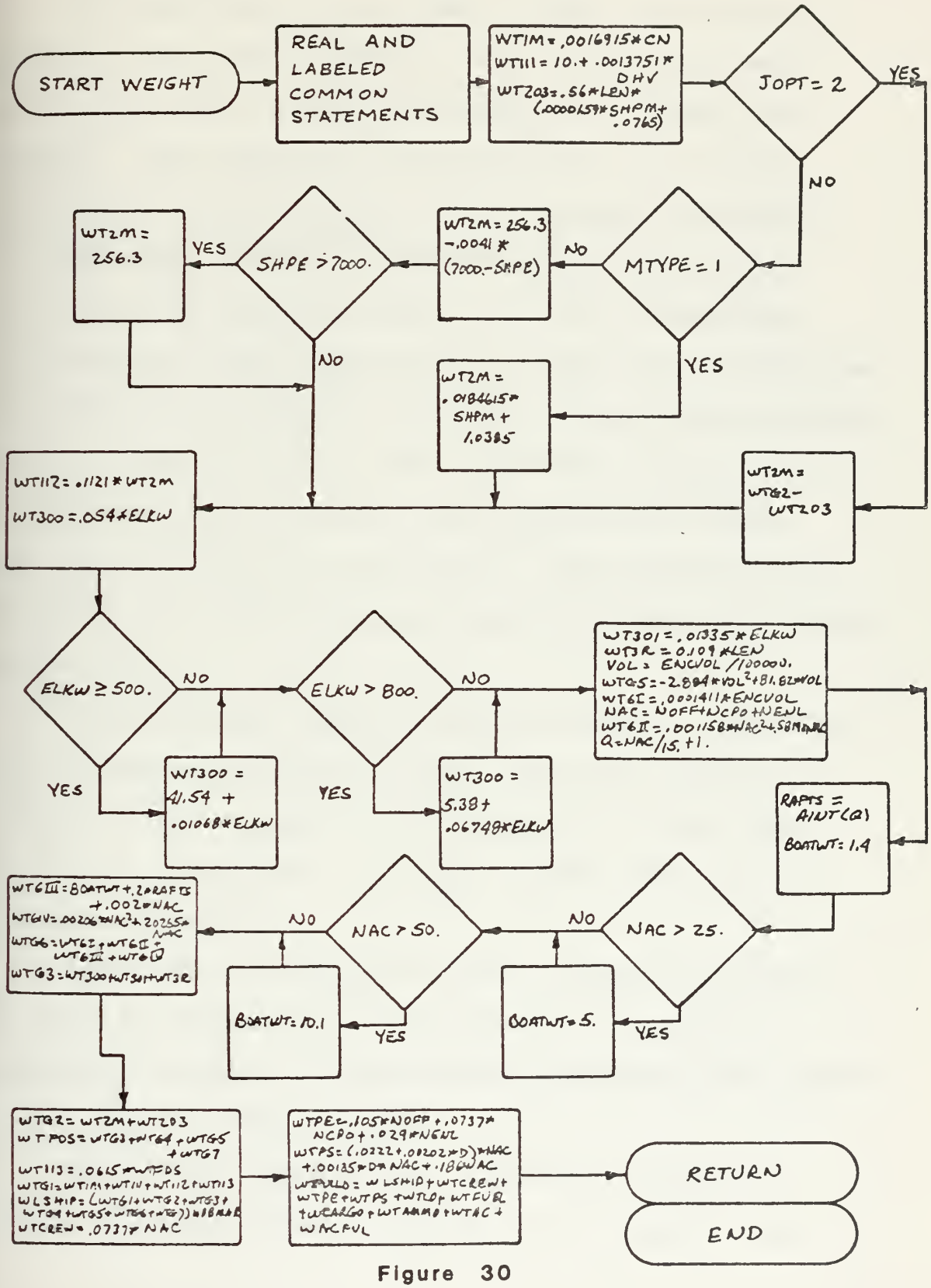

START WEIGHT
REAL AND LABELED COMMON STATEMENTS
WTIM = .0016915*CN
WTIII = 10. + .0013751* DHV
WT203 = .56*LEN* (.0000159*SHPM + .0765)
JOPT = 2
YES
NO
MTYPE = 1
NO
WT2M = 256.3 -.0041 * (7000.-SHPE)
SHPE > 7000.
YES
WT2M = 256.3
NO
YES
WT2M = .0184615* SHPM + 1.0385
WT112 = .1121 * WT2M
WT300 = .054*ELKW
WT2M = WTG2 - WT203
ELKW ≥ 500.
NO
YES
WT300 = 41.54 + .01068*ELKW
ELKW > 800.
NO
YES
WT300 = 5.38 + .06748*ELKW
WT301 = .01335*ELKW
WT3R = 0.109*LEN
VOL = ENCVOL / 120000.
WTGS = -2.884*VOL² + 81.82*VOL
WT6I = .0001411*ENCVOL
NAC = NOFF + NCPO + NENL
WT6II = .00115B*NAC² + 4.58*NAC
Q = NAC/15. + 1.
RAFTS = AINT(Q)
BOATWT = 1.4
WTG III = BOATWT + .2*RAFTS + .002*NAC
WTGIV = .00206*NAC² + 2.0255* NAC
WTG6 = WT6I + WT6II + WT6III + WT6IV
WTG3 = WT300 + WT301 + WT3R
NAC > 50.
NO
YES
BOATWT = 10.1
NAC > 25.
NO
YES
BOATWT = 5.
WTG2 = WT2M + WT203
WTPOS = WTG3 + WTG4 + WTG5 + WTG7
WT113 = .065*WTPOS
WTGI = WTIII + WTIV + WT112 + WT113
WLSHIP = (WTG1 + WTG2 + WTG3 + WTG4 + WTG5 + WTG6 + WTG7)
WTCREW = .0737* NAC
WTPE = .105*NOFF + .0737* NCPO + .029*NENL
WTPS = (.0322 + .00202*D)*NAC + .00135*D*NAC + .186*NAC
WFUEL = WLSHIP + WTCREW + WTPE + WTPS + WTLO + WTFUEL + WTCARGO + WTAMMO + WTAC + WACFUL
RETURN
END

Figure 30

either load weight calculations or from inclining experiment data.

The first hull weight group is the hull structure, group 1. In order to estimate this weight group more accurately, three of the sub-groups are estimated separately. The remainder of the sub-groups are lumped together as a single group. In the program this group is referred to as WT1M. The three groups subtracted are group 111, superstructure; group 112, foundations for propulsion plant machinery; and group 113, foundations for auxiliaries and other equipment. These are identified in the program as WT111, WT112, and WT113, respectively.

Figure 31 is a plot of WT1M versus cubic number. The correlation here is very good. Also included on the figure is the estimating line used in the Navy's destroyer model, DD07.

Superstructure weight, WT111, is shown in Figure 32. plotted against deckhouse volume. The line labeled no uptakes is the one used in the program. The line used in DD07 is also shown. This line assumes that the deckhouse is aluminum.

The weight of propulsion plant foundations, WT112, is shown in Figure 33 plotted against the weight of propulsion machinery minus shafting and propellers. Again, a line used in DD07 is shown.

WT113, other foundations, is shown in Figure 34 versus the total weight of groups 3, 4, 5, and 7. The

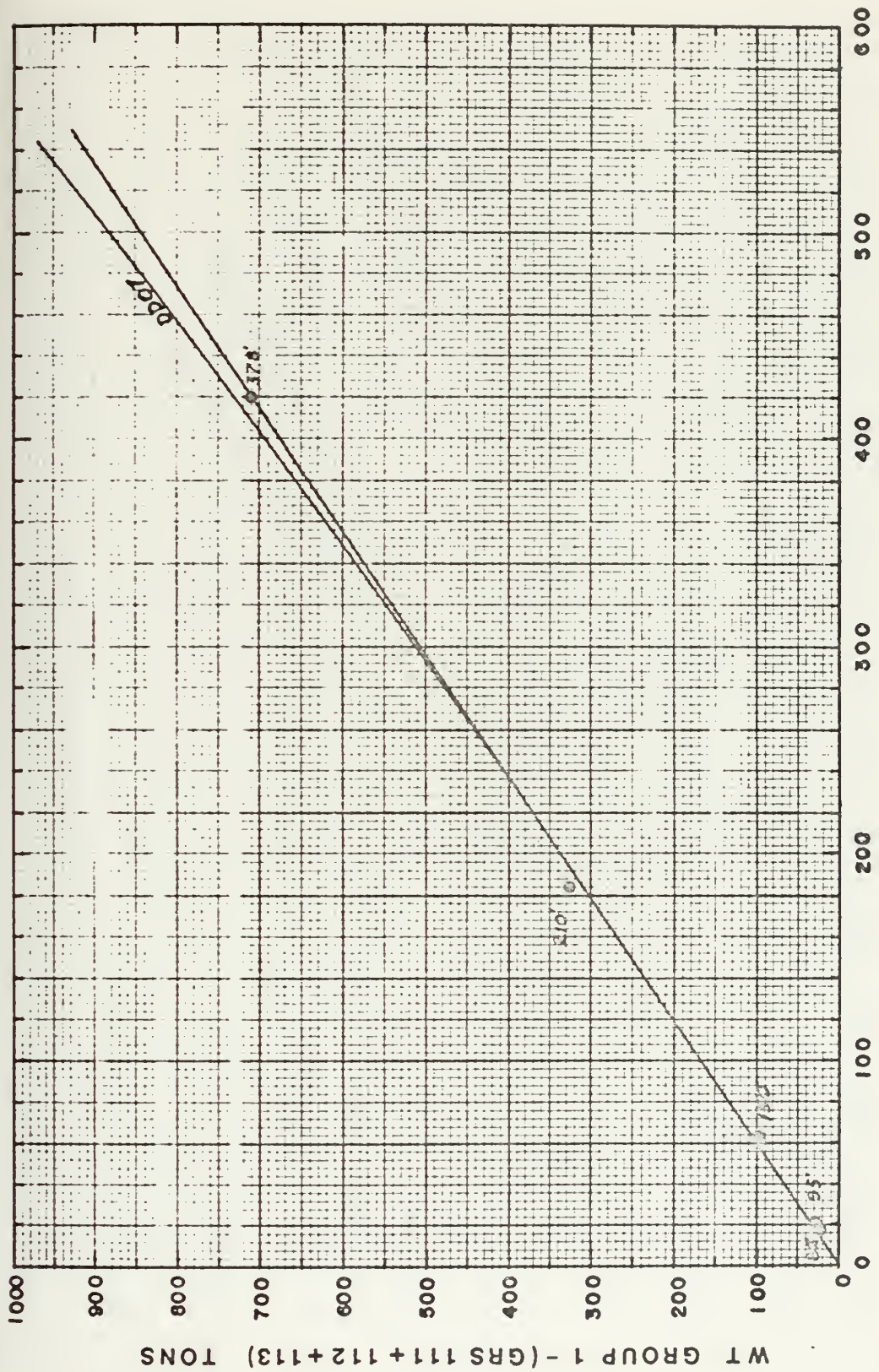

WT GROUP 1 -(GRS 111+112+113) TONS
CUBIC No. x10$^{-3}$ (CU FT)
1000
900
800
700
600
500
400
300
200
100
0
100
200
300
400
500
600
1000
176'
210'
95'

Figure 31

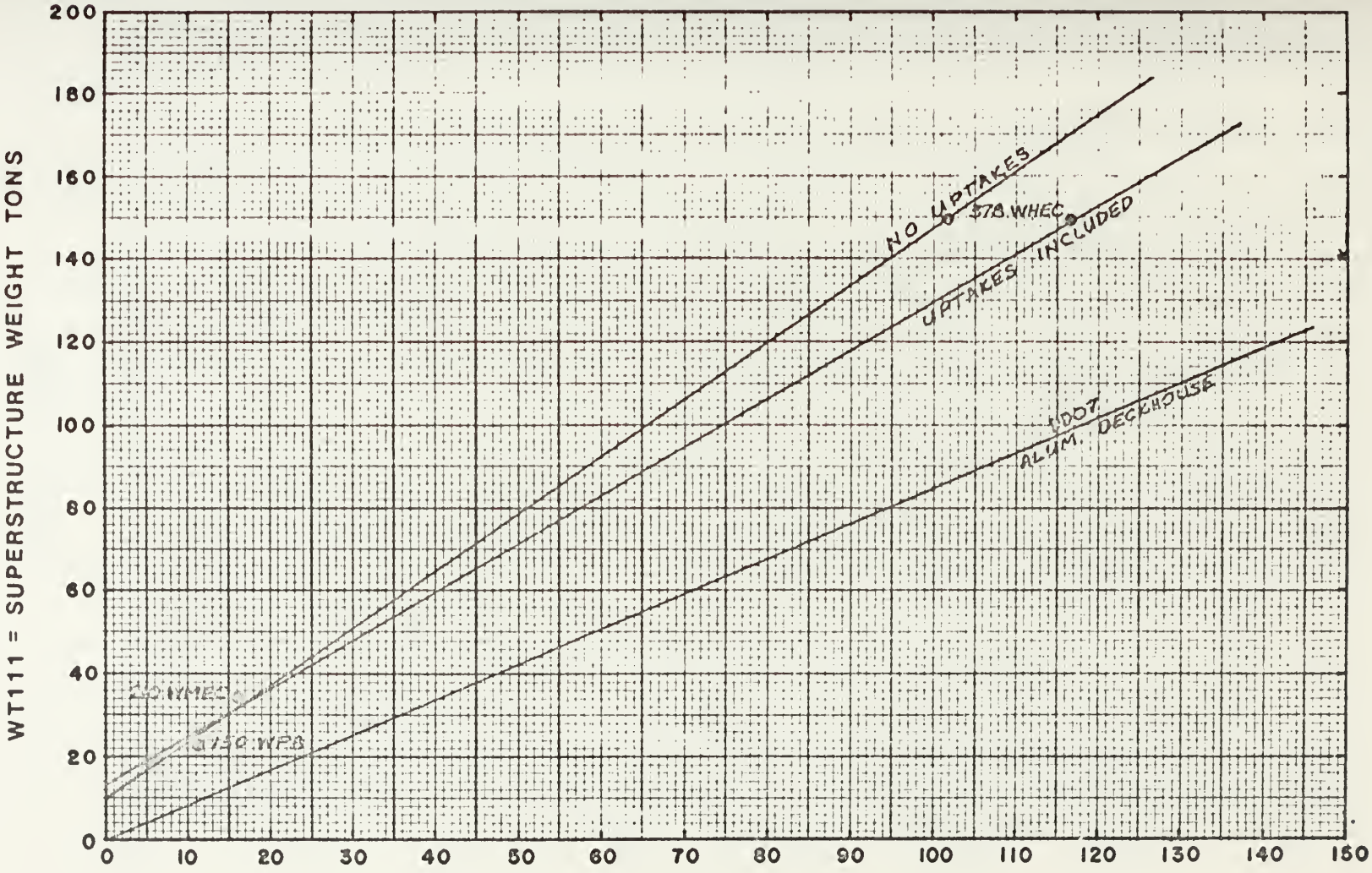
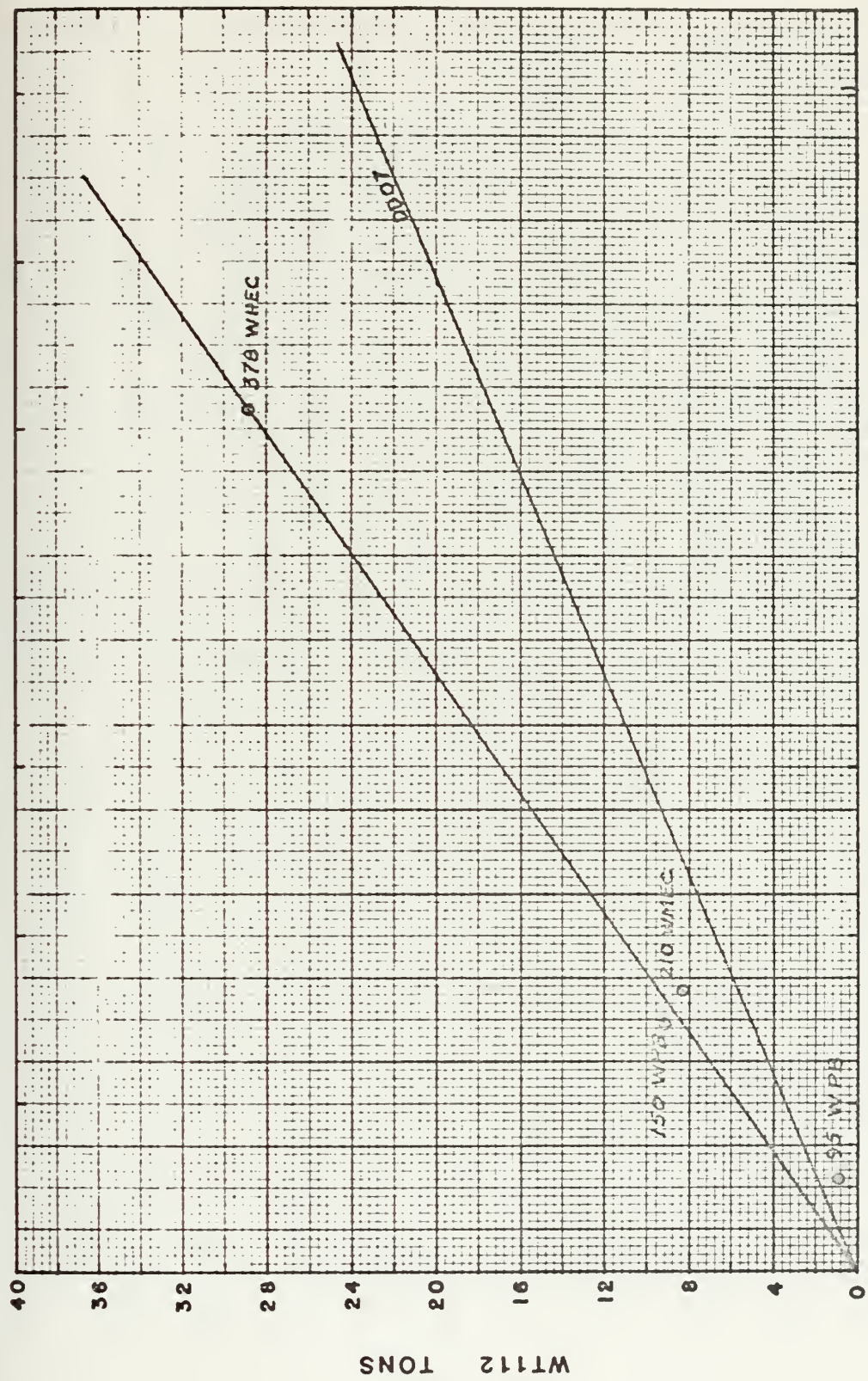

WT111 = SUPERSTRUCTURE WEIGHT TONS
200
180
160
140
120
100
80
60
40
20
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
NO UPTAKES
$78. WHEC
UPTAKES INCLUDED
HDDT
ALUM. DECKHOUSE
DECKHOUSE VOLUME x 10⁻³ (CU FT)

Figure 32




WT2M = WTG2 - WT203 TONS

Figure 33

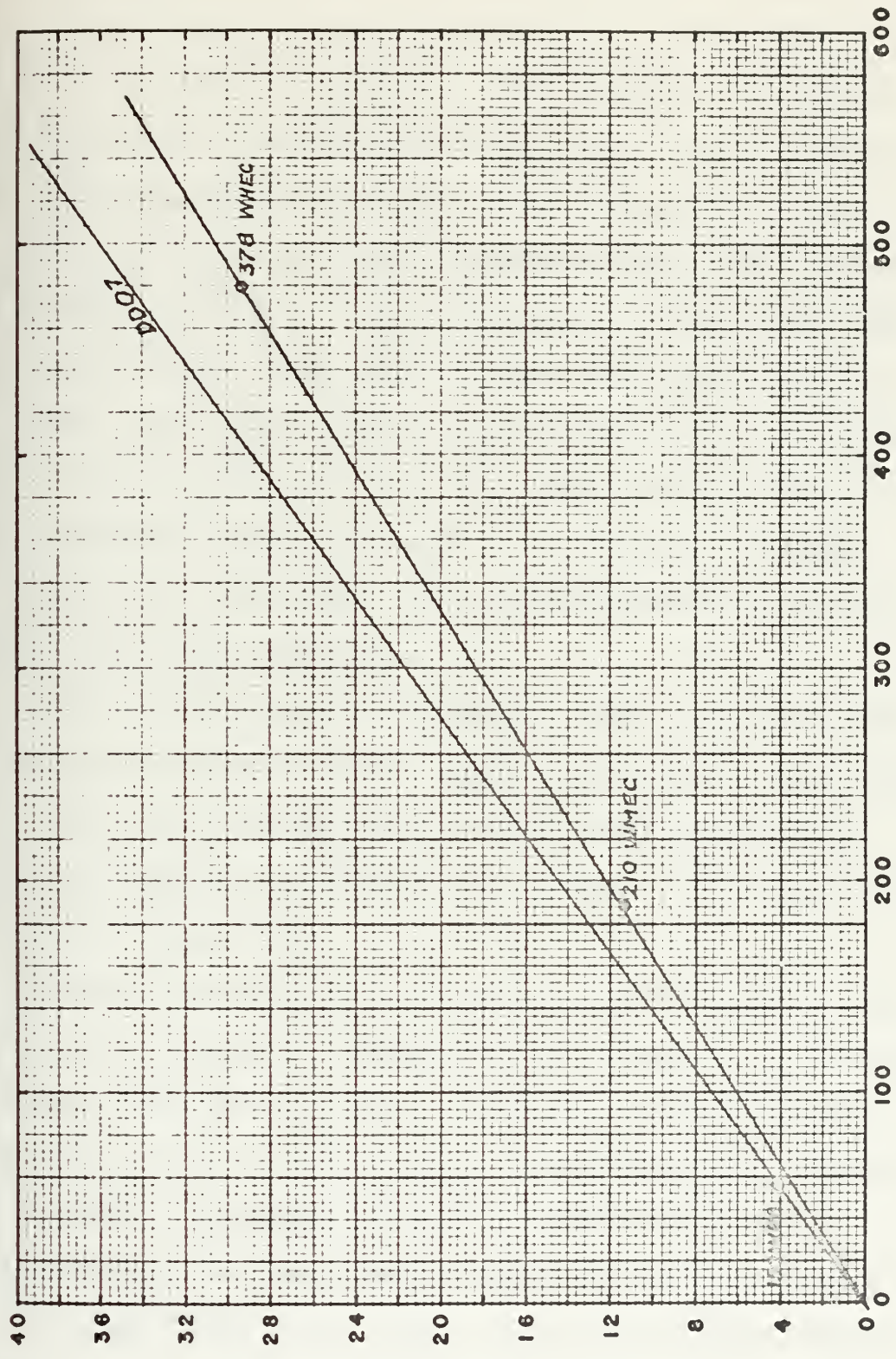

WTG3+WTG4+WTG5+WTG7 TONS
0
4
8
12
16
20
24
28
32
36
40
100
200
300
400
500
600
Φ378 WMEC
Φ210 WMEC

Figure 34

correlation here appears reasonable; however, there is a difference between the data and the DD07 estimate.

Propulsion machinery is classified under group 2. In this program, an estimate of the weight of sub-group 203 (shafting, bearings, and propellers) was made separately. The remaining sub-groups were estimated as one group, WT2M. A plot of WT2M versus shaft horsepower for diesel plants is shown in Figure 35. Here more data is available from non patrol types. The DD07 estimate for diesel plants is poor. For CODOG plants it is assumed that the diesel plant will be 7000 horsepower or under and that only the endurance power will cause a difference in weight from that of a 378' WHEC. A lower endurance power will reduce the weight somewhat.

Shafting and propeller weight, WT203, is calculated as weight per foot of shaft length versus shaft horsepower. Twin shafts are assumed with a total shaft length 0.56 times the length of the ship. A plot of this relationship is shown in Figure 36.

Group 3 includes the electrical plant weights. The Coast Guard intends to install electric plants of relatively larger capacity in future ships so a simple linear estimation using current designs is unrealistic. Instead, the weights of a number of diesel generating sets of various capacities have been plotted as shown in Figure 37. The varying RPM of these plants resulted in three weight ranges.

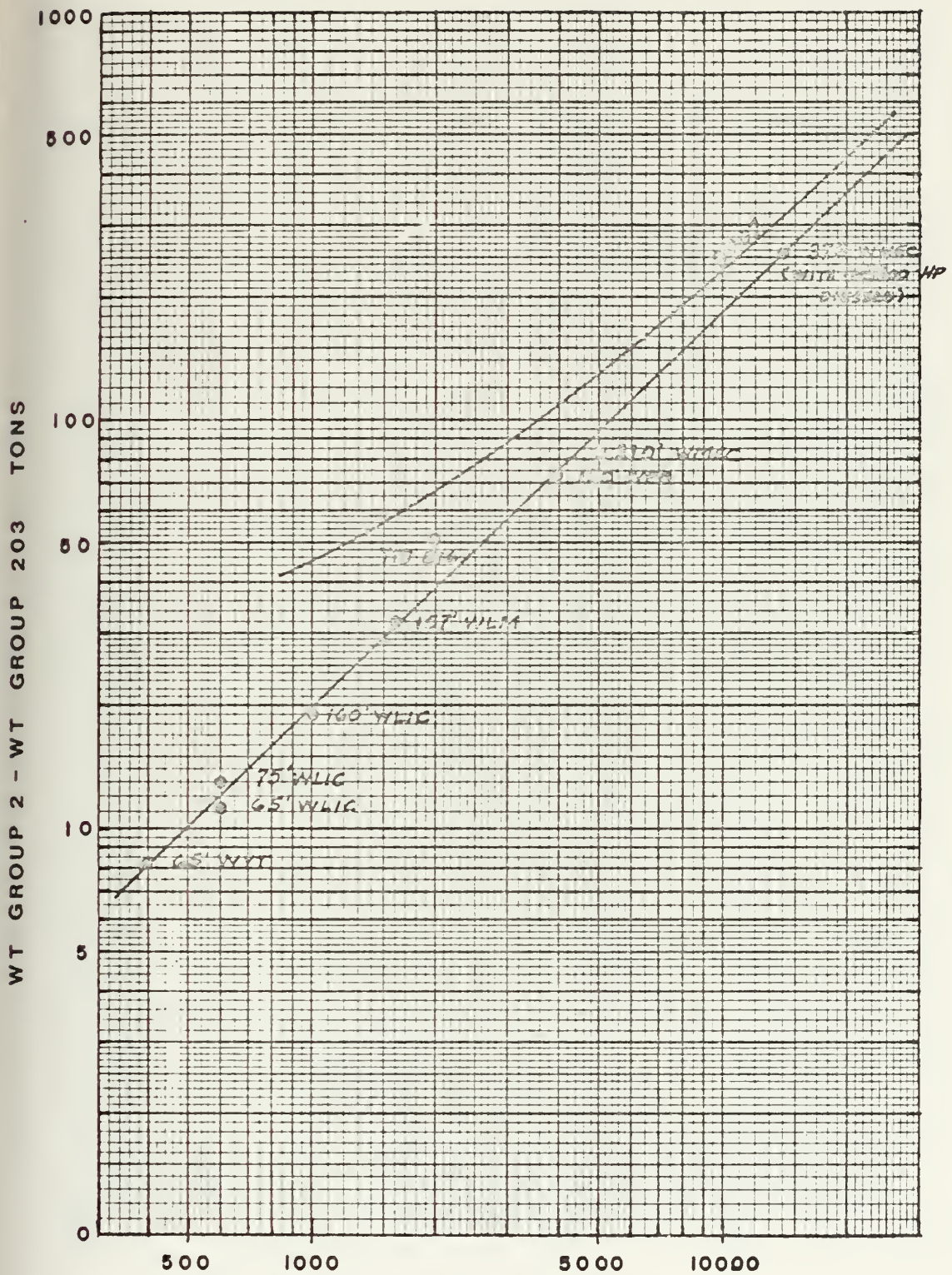

1000
500
100
50
10
5
0
500
1000
5000
10000
WT GROUP 2 - WT GROUP 203 TONS
SHAFT HORSEPOWER
75' WLIC
65' WLIC
65' WYT
160' WLIC
197' WLIC
HP

Figure 35

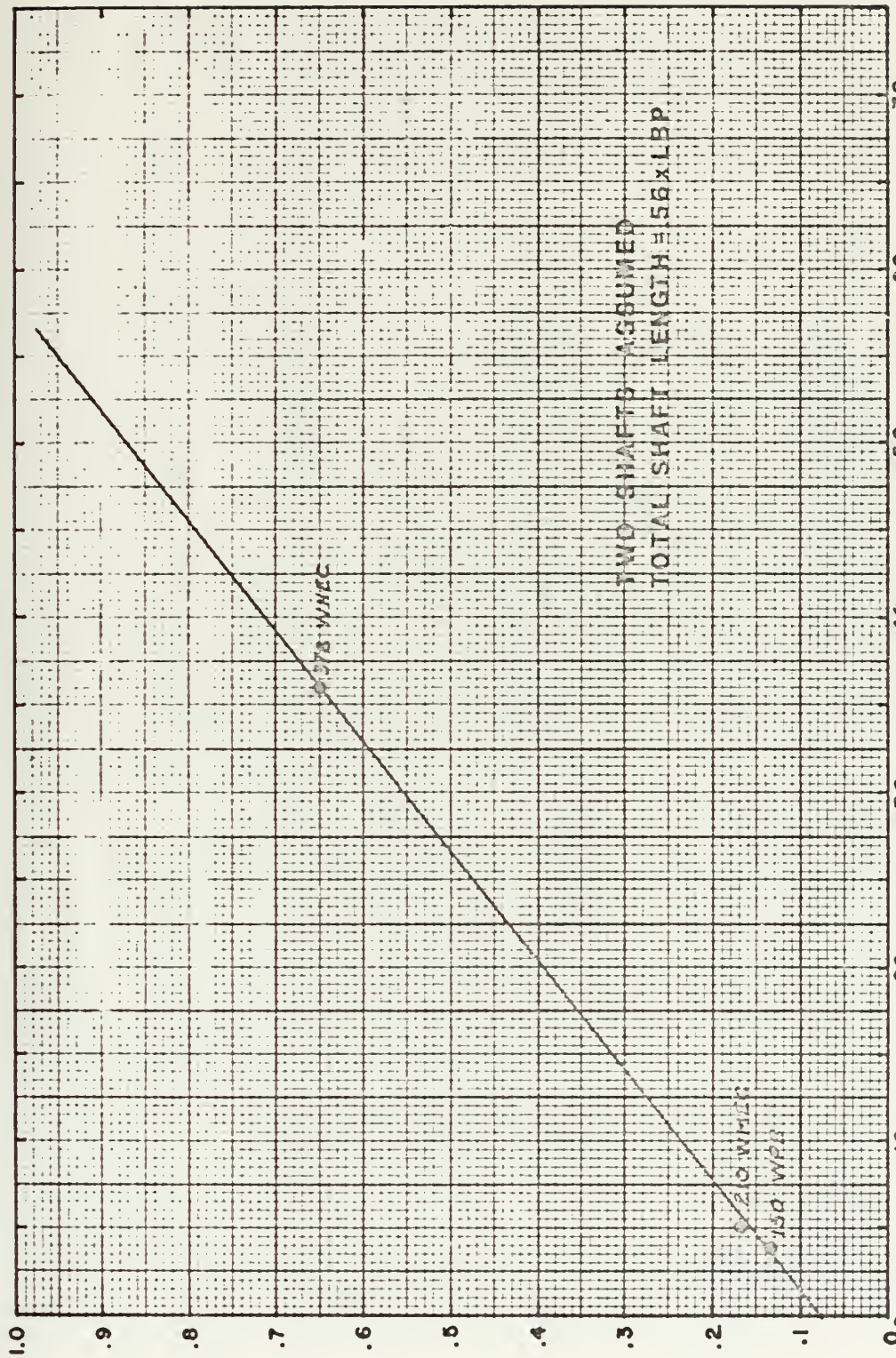

WT203/SHAFT LENGTH TONS/FT
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0.0
10
20
30
40
50
60
70
SHAFT HORSEPOWER x 10⁻³
TWO SHAFTS ASSUMED
TOTAL SHAFT LENGTH = .56 x LBP
378 RPM
210 RPM
150 RPM

Figure 36

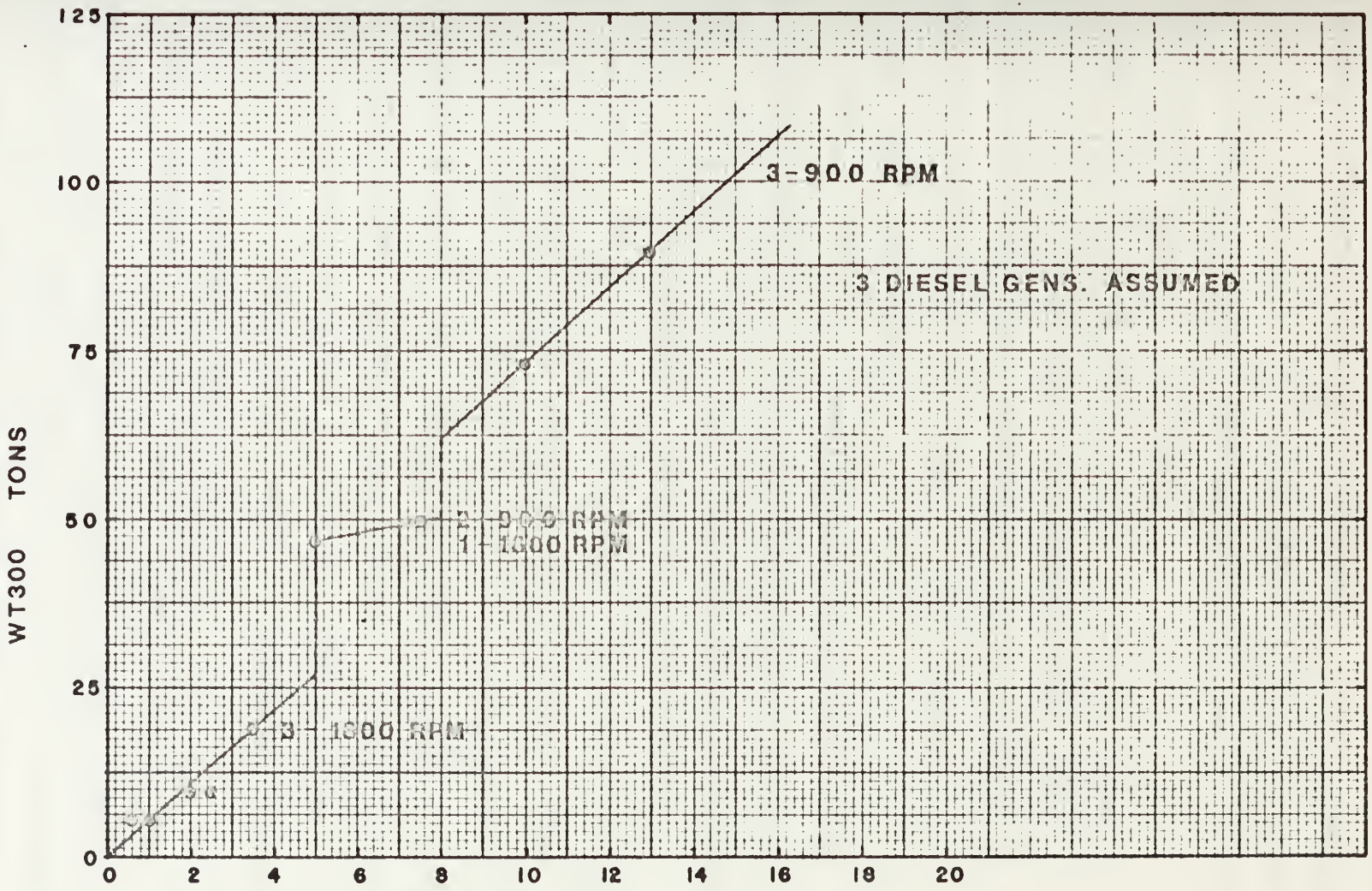

125
100
75
50
25
0
WT300 TONS
0
2
4
6
8
10
12
14
16
18
20
3-900 RPM
3 DIESEL GENS. ASSUMED
2-900 RPM
1-1800 RPM
3-1800 RPM
RATED KW/GENERATOR x 10^-2

Figure 37

The weight of the generating sets is only a part of the group 3 weight. The weight of switchboards, WT301, is shown in Figure 38 as is the remaining group 3 weight, WT3R. The correlation for these weight groups is quite bad. Fortunately, these weights make up a small percentage of the total weight of the ship.

Since group 4 weights are given as input, group 5 weights, auxiliary systems, is estimated next. The destroyer model uses the estimating relation shown in Figure 39. The three Coast Guard vessels agree very well with this relationship .

Group 6, outfit and furnishings is the last light ship group estimated since group 7 weights are given as input. Group 6 is broken into four sub-groups for estimating purposes. The first, WT6I, includes groups 600, 602, 603, and 605. These are hull fittings, rigging and canvas, ladders and gratings, and painting, respectively. The second group, WT6II, includes groups 604, nonstructural bulkheads and doors; 606, deck covering; 607, hull insulation; and 608, storerooms, stowages and lockers. Group three, WT6III, includes only group 601, boats, boat stowage and handling. The final group, WT6IV, includes all the remaining sub-groups of weight group 6.

WT6I plotted against enclosed volume is shown in Figure 40. WT6II and WT6IV are plotted against number of accommodations as shown in Figure 41. WT6III is estimated in three parts. The first is a boat weight, the second a

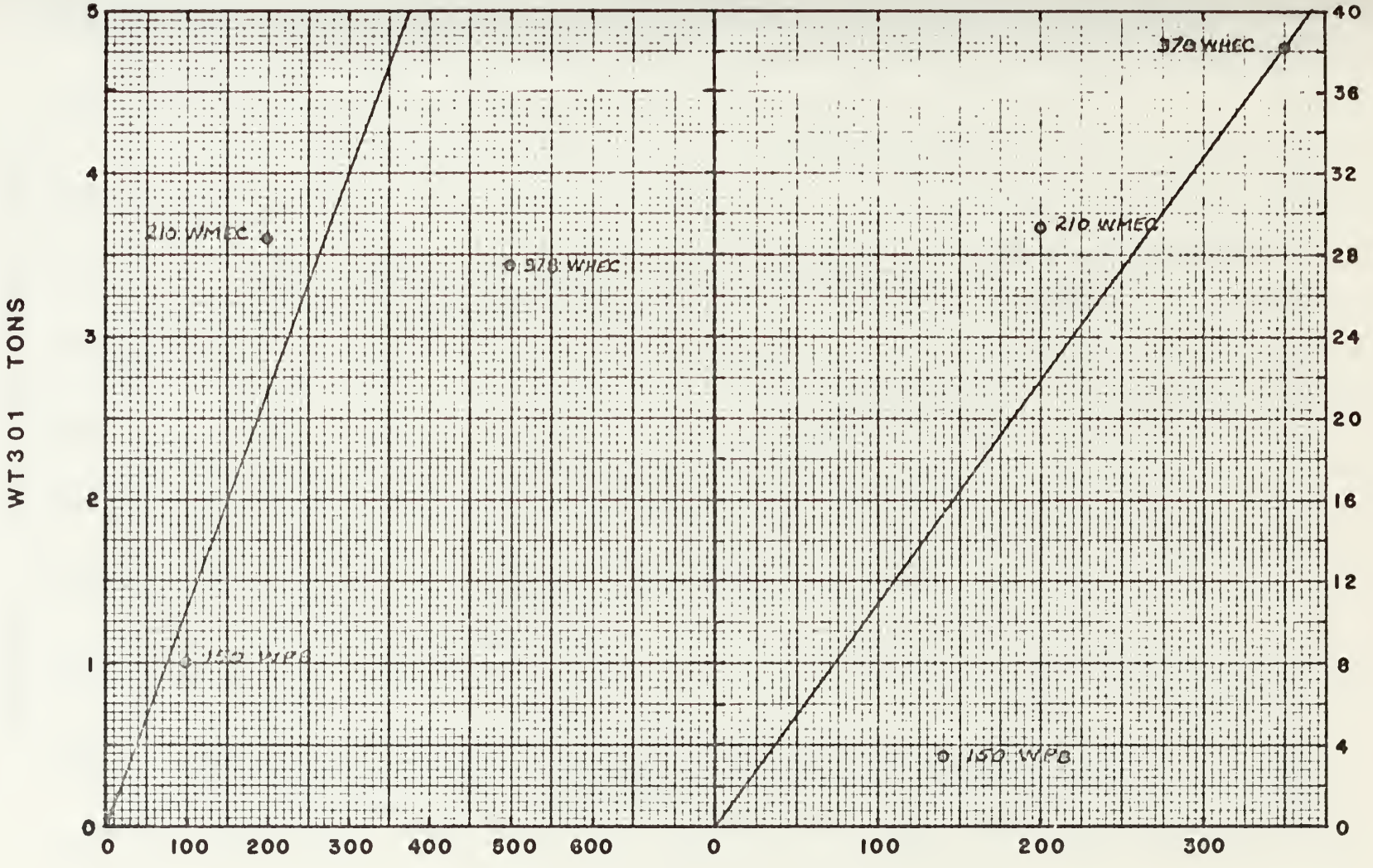
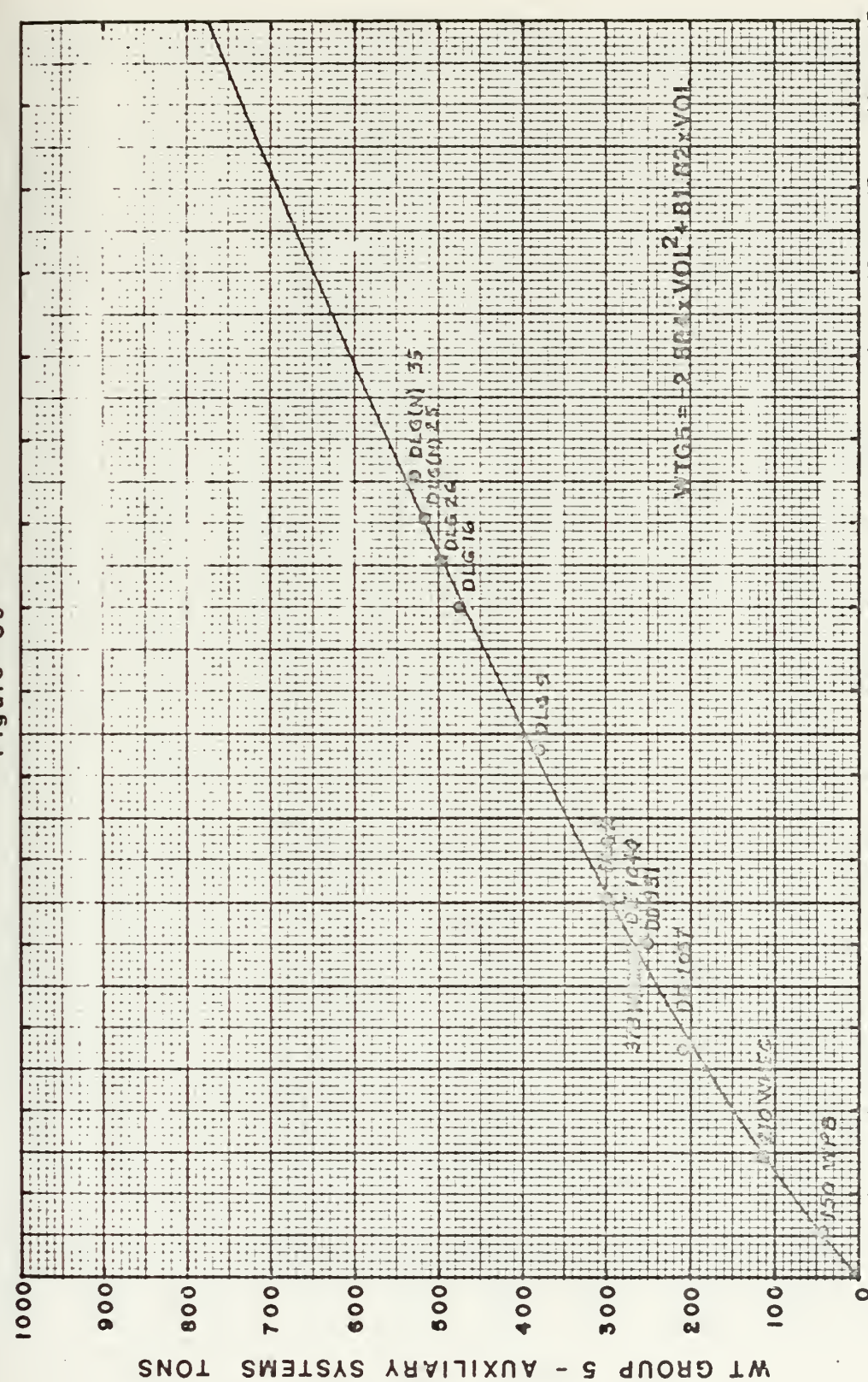
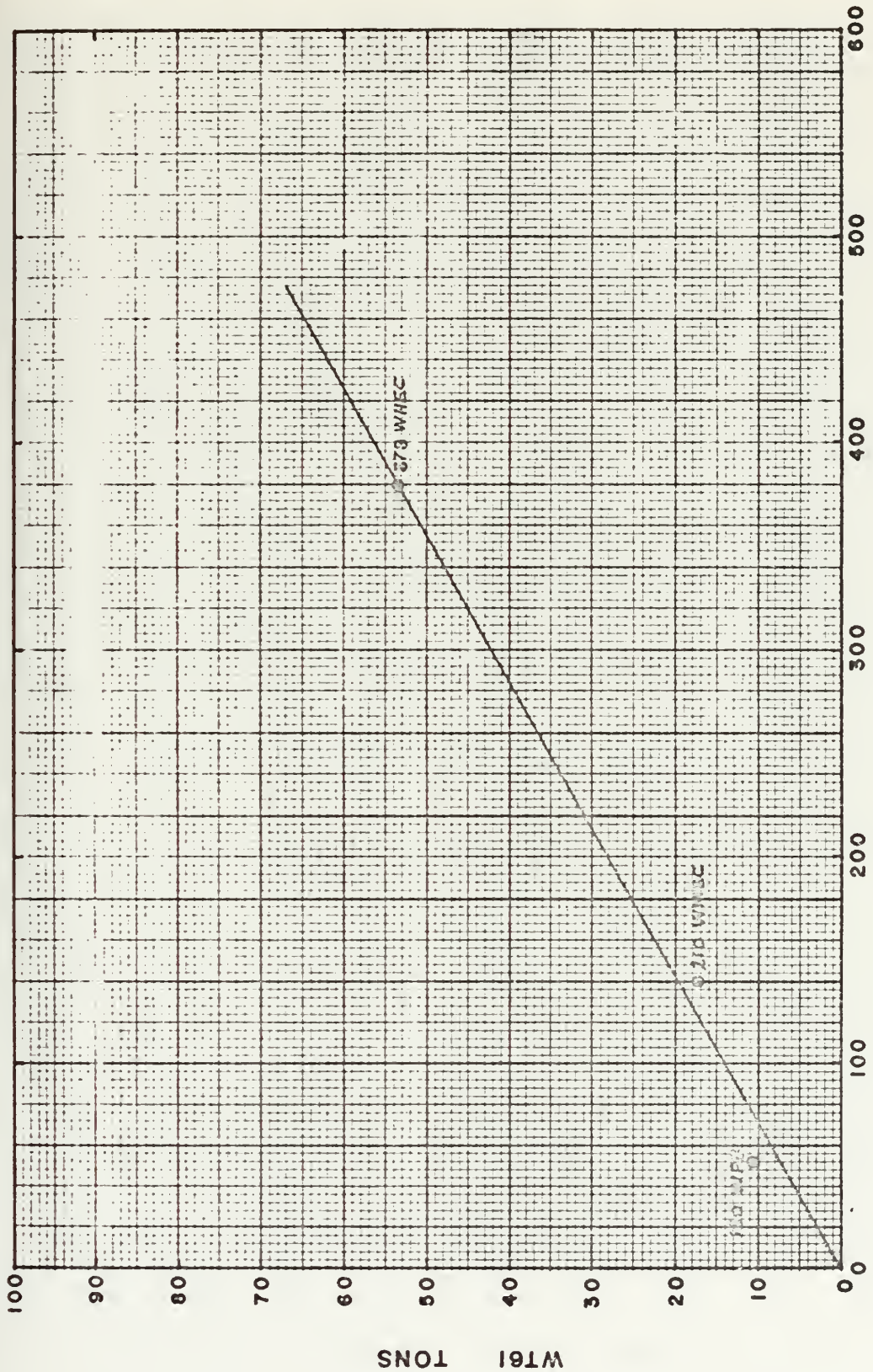

WT301 TONS
WT3R TONS
KW/GEN
LBP FT
210 WMEC
378 WHEC
150 WPB
210 WMEC
378 WHEC
150 WPB
0
1
2
3
4
5
0
100
200
300
400
500
600
0
100
200
300
0
4
8
12
16
20
24
28
32
36
40

Figure 38


WT GROUP 5 - AUXILIARY SYSTEMS TONS
1000
900
800
700
600
500
400
300
200
100
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
VOL
TOTAL ENCLOSED VOLUME x $10^{-5}$
DLG(N) 35
DLG(N) 25
DLG 24
DLG 16
DDG 51
DD 963
DD 931
DD 963
DD 931
DD 963
DD 931




ENCLOSED VOLUME x $10^{-3}$

Figure 40

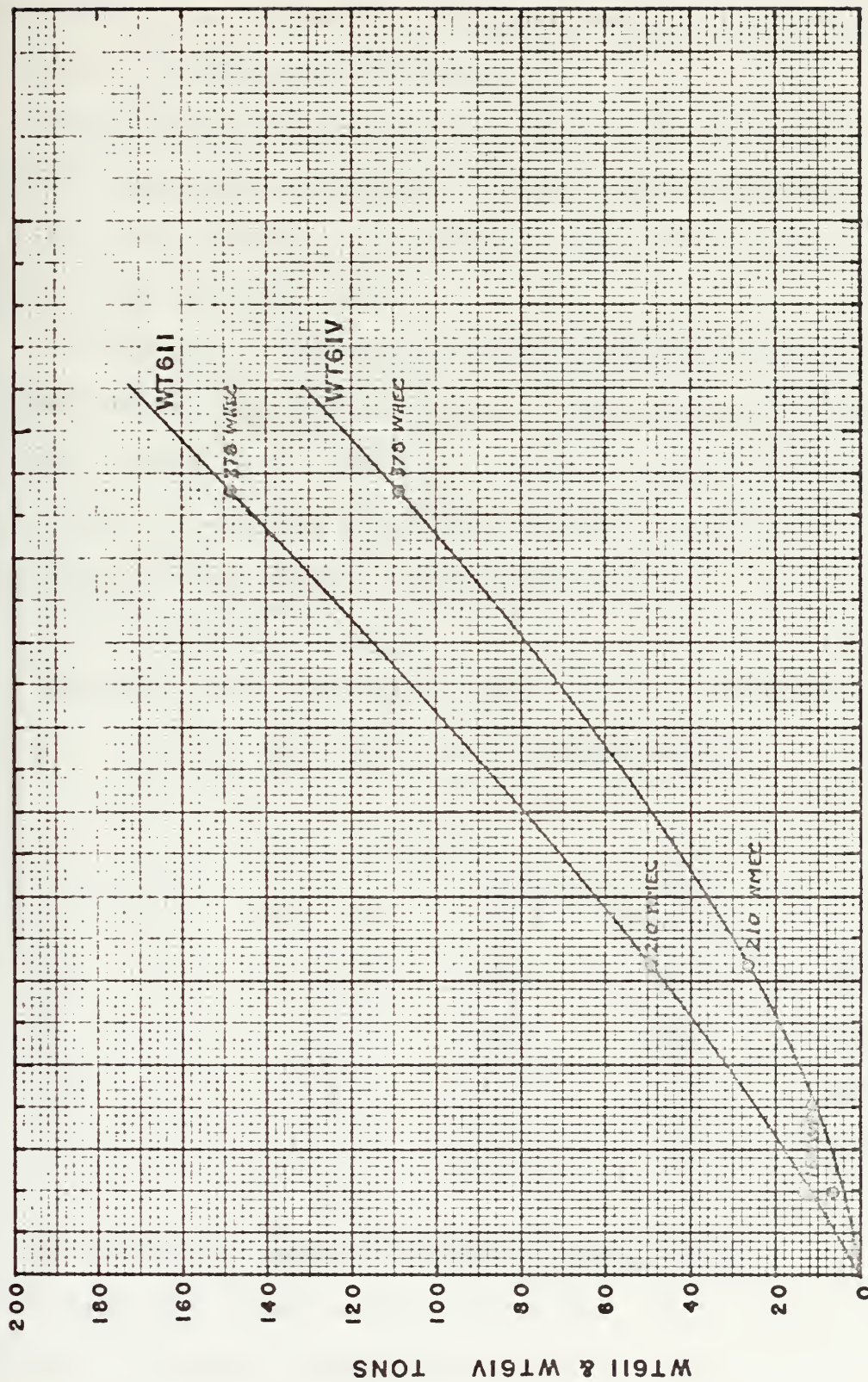

WT611
WT61V
370 WMEC
370 WMEC
270 WMEC
210 WMEC
WT611 & WT61V TONS
No. of ACCOMMODATIONS
0
20
40
60
80
100
120
140
160
180
200
50
100
150
200
250

Figure 41

liferaft weight and the third a lifejacket weight.

All of the lightship weights are summed and then multiplied by a design and builders margin. The design and builders margin is an input.

Crew weight is taken to be 0.0737 tons per man or 165 pounds per man. Personal effects are calculated as 0.105 tons per man for officers, .0737 for chiefs and .029 for enlisted men.

The weight of personnel stores includes provisions, general stores, and potable water. The weight of provisions is based on Table 3. The data in this table was reduced to a formula for which only the endurance days of dry provisions need be given. This formula is:

(.0222+.00202 x D) x NAC

where D is the endurance days for dry provisions

NAC is the number of accommodations

Table 3

| days endurance | pounds/person | | | |
|---|---|---|---|---|
| | dry prov. | frozen | chilled | total |
| 30 | 97.0 | 36.8 | 51.8 | 185.6 |
| 45 | 145.5 | 55.2 | 52.8 | 253.5 |
| 60 | 194.0 | 73.6 | 53.8 | 321.4 |
| 90 | 291.0 | 110.4 | 55.8 | 457.2 |

The weight of general stores is taken to be

.00135 x D x NAC

and that of potable water to be

.186 x NAC or 50 gallons/man

The full load weight can then be calculated by adding the load weights to the light ship weight.

3.12.2 Input List for Subroutine WEIGHT

| | |
|---|---|
| CN.....LC(BB) | SHPE.....LC(CC) |
| D.....LC(AA) | SHPM.....LC(CC) |
| DBMAR.....LC(WW) | WACFUL.....LC(LL) |
| DHV.....LC(BB) | WCARGO.....LC(LL) |
| ELKW.....LC(DD) | WTAC.....LC(LL) |
| ENCVOL.....LC(BB) | WTAMMO.....LC(LL) |
| JOPT.....LC(CC) | WTFUEL.....LC(LL) |
| LEN.....LC(BB) | WTG2*.....LC(WW) |
| MTYPE.....LC(CC) | WTG4.....LC(WW) |
| NCPO.....LC(AA) | WTG7.....LC(WW) |
| NENL.....LC(AA) | WTLO.....LC(LL) |
| NOFF.....LC(AA) | |

*only if JOPT = 2

3.12.3 Statement Descriptions

A detailed description of each statement will not be given for this routine wince the flow of the program follows the description given in the introduction and the relationships are those plotted.

One area that will be discussed is WT6III. Here the number of 15 man liferafts required is first calculated.

```
Q=NAC/15.+1.
RAFTS=AINT(Q)
```

where AINT is a function which drops the decimal fraction

from its argument. Boat weight is assumed to be 1.4 tons up to 25 men, 5 tons between 25 and 50 men and 10.1 tons above 50 men. This weight includes launching equipment. Lifejacket weight is taken to be .002 tons per man.

3.12.4 Output List for Subroutine WEIGHT

| | |
|---|---|
| WFULLD.....LC(WW) | WT6II.....LC(VV) |
| WLSHIP.....LC(WW) | WT6III.....LC(VV) |
| WT111.....LC(VV) | WT6IV.....LC(VV) |
| WT112.....LC(VV) | WTCREW.....LC(LL) |
| WT113.....LC(VV) | WTG1.....LC(WW) |
| WT1M.....LC(VV) | WTG2*.....LC(WW) |
| WT203.....LC(VV) | WTG3.....LC(WW) |
| WT2M.....LC(VV) | WTG5.....LC(WW) |
| WT300.....LC(VV) | WTG6.....LC(WW) |
| WT301.....LC(VV) | WTPE.....LC(LL) |
| WT3R.....LC(VV) | WTPS.....LC(LL) |
| WT6I.....LC(VV) | |

* only if JOPT = 1

3.12.5 Nomenclature List

The definition of all variables is the same as given in the MAIN program nomenclature except for the following:

| | |
|---|---|
| BOATWT | boat weight, tons |
| D | same as ENDDAY in MAIN |
| NAC | number of accommodations |
| Q | dummy argument |

| | |
|---|---|
| RAFTS | number of liferafts |
| RE | same as RGEND in MAIN |
| SFCH | same as SFCHHP in MAIN |
| SFCM | same as SFCMHP in MAIN |
| VE | same as VEND in MAIN |
| VOL | enclosed volume x $10^{-5}$ |
| WT111 | weight of group 111, tons |
| WT112 | weight of group 112, tons |
| WT113 | weight of group 113, tons |
| WT1M | weight of remainder of group 1, tons |
| WT203 | weight of group 203, tons |
| WT2M | weight of remainder of group 2, tons |
| WT300 | weight of group 300, tons |
| WT301 | weight of group 301, tons |
| WT3R | weight of remainder of group 3, tons |
| WT6I | see text |
| WT6II | see text |
| WT6III | see text |
| WT6IV | see text |
| WTFDS | sum of weight groups 3, 4, 5, and 7 |

## 3.13 Subroutine VCG

### 3.13.1 Introduction

The vertical center of gravity of the ship is estimated in this routine. The designer has some latitude with regard to the location of the center of gravity; therefore, the value calculated by this routine should be viewed as a feasible rather tnan as the best value.

The effect that the vcg has on the design can be investigated by using different values of free surface correction. The free surface correction is added to the KG. Therefore, either a positive or a negative value can be used to represent a shift in the KG location.

In order to determine feasible locations for the various centers, data for the 378' WHEC, the 210' WMEC, and the 150' WPB was used. This data is shown in Tables 4 and 5. On these tables the vcgs of the various weight groups are shown. These centers are related to various hull depths by a factor K. The hull depth used is given in the right hand column of these tables. An average coefficient, K, was chosen and is given in the column labeled Coef. K.

The variables to which the vcgs are referred were chosen arbitrarily by observing which gave the most consistent set of coefficients among the three ships.

Some of the weight groups shown in the tables are really input items. These weight groups are included to assist the designer in choosing realistic values to

## VERTICAL CENTERS OF GRAVITY

| Weight | | 378' WHEC | 210' WMEC | 150' WPB | Coef. K | times |
|---|---|---|---|---|---|---|
| WT1M | vcg | 15.78 | 14.72 | 9.55 | | |
| | K | .553 | .547 | .584 | .55 | DAVG |
| WT111 | vcg | 37.1 | 35.3 | 23.6 | | |
| | K | 1.4 | 1.26 | 1.47 | 1.4 | D10 |
| WT112 | vcg | 5.73 | 4.4 | 2.5 | | |
| | K | .216 | .157 | .156 | .2 | D10 |
| WT113 | vcg | 21.05 | 16.6 | 15.1 | | Center groups |
| | K | .794 | .593 | .944 | .87 | 3+4+5+7 |
| WT2M | vcg | 15.14 | 10.40 | 8.50 | | |
| | K | .571 | .533 | .531 | .54 | D10MN |
| WT203 | vcg | 4.02 | 6.0 | 2.6 | | |
| | K | .152 | .214 | .163 | .16 | D10 |
| WT300 | vcg | 20.35 | 14.7 | 19.0 | | |
| | K | .768 | .525 | 1.19 | .7 | D10 |
| WT301 | vcg | 21.3 | 11.8 | 21.0 | | |
| | K | .804 | .421 | 1.31 | .8 | D10 |
| WT3R | vcg | 27.5 | 19.41 | 17.79 | | |
| | K | 1.038 | .693 | 1.11 | 1.0 | D10 |
| WTG5 | vcg | 19.43 | 16.68 | 13.5 | | |
| | K | .733 | .596 | .844 | .71 | D10 |
| WT6I | vcg | 20.66 | 20.43 | 15.09 | | |
| | K | .78 | .73 | .943 | .75 | D10 |
| WT6II | vcg | 26.48 | 21.93 | 19.23 | | |
| | K | 1.0 | .783 | 1.2 | 1.0 | D10 |
| WT6III | vcg | 41.75 | 33.9 | 25.9 | | |
| | K | 1.575 | 1.738 | 1.62 | 1.6 | D10MN |
| WT6IV | vcg | 24.88 | 20.97 | 13.46 | | |
| | K | .939 | .749 | .841 | .84 | D10 |
| WTG4 | vcg | 31.56 | 35.0 | 22.6 | | |
| | K | 1.191 | 1.25 | 1.41 | 1.3 | D10 |
| WTG7 | vcg | 35.26 | 24.45 | 21.3 | | |
| | K | 1.33 | .873 | 1.33 | 1.3 | D10 |

Table 4

## VERTICAL CENTERS OF GRAVITY

| Weight | | 378' WHEC | 210' WMEC | 150' WPB | Coef. K | times |
|---|---|---|---|---|---|---|
| Crew & Personal Effects | vcg | 26.26 | 20.43 | 15.0 | | |
| | K | .964 | 1.048 | .938 | .97 | D10MN |
| Provisions | vcg | 15.0 | 15.0 | 11.0 | | |
| | K | .55 | .536 | .688 | .55 | D10 |
| General Stores | vcg | 24.05 | 16.16 | 11.0 | | |
| | K | .883 | .829 | .688 | .85 | D10MN |
| Ammo | vcg | 15.99 | 8.4 | 19.0 | | |
| | K | .587 | .431 | 1.19 | .5 | D10MN |
| Potable Water | vcg | 7.06 | 8.5 | 4.2 | | |
| | K | .26 | .30 | .263 | .26 | D10 |
| L.O. | vcg | 3.58 | 2.5 | 12.0 | | |
| | K | .131 | .128 | .75 | .13 | D10MN |
| Fuel | vcg | 7.67 | 8.17 | 6.6 | | |
| | K | .281 | .292 | .412 | .3 | D10 |
| Aircraft | vcg | 39.01 | | | | |
| | K | 1.43 | | | 1.4 | D10 |
| A/C Fuel | vcg | 9.56 | | | | |
| | | .351 | | | .351 | D10 |
| DAVG | | 28.54 | 26.91 | 16.36 | | |
| D10 | | 27.25 | 28.0 | 16.0 | | |
| D10MN | | 27.25 | 19.5 | 16.0 | | |

Table 5

# VCG SUBROUTINE FLOW CHART

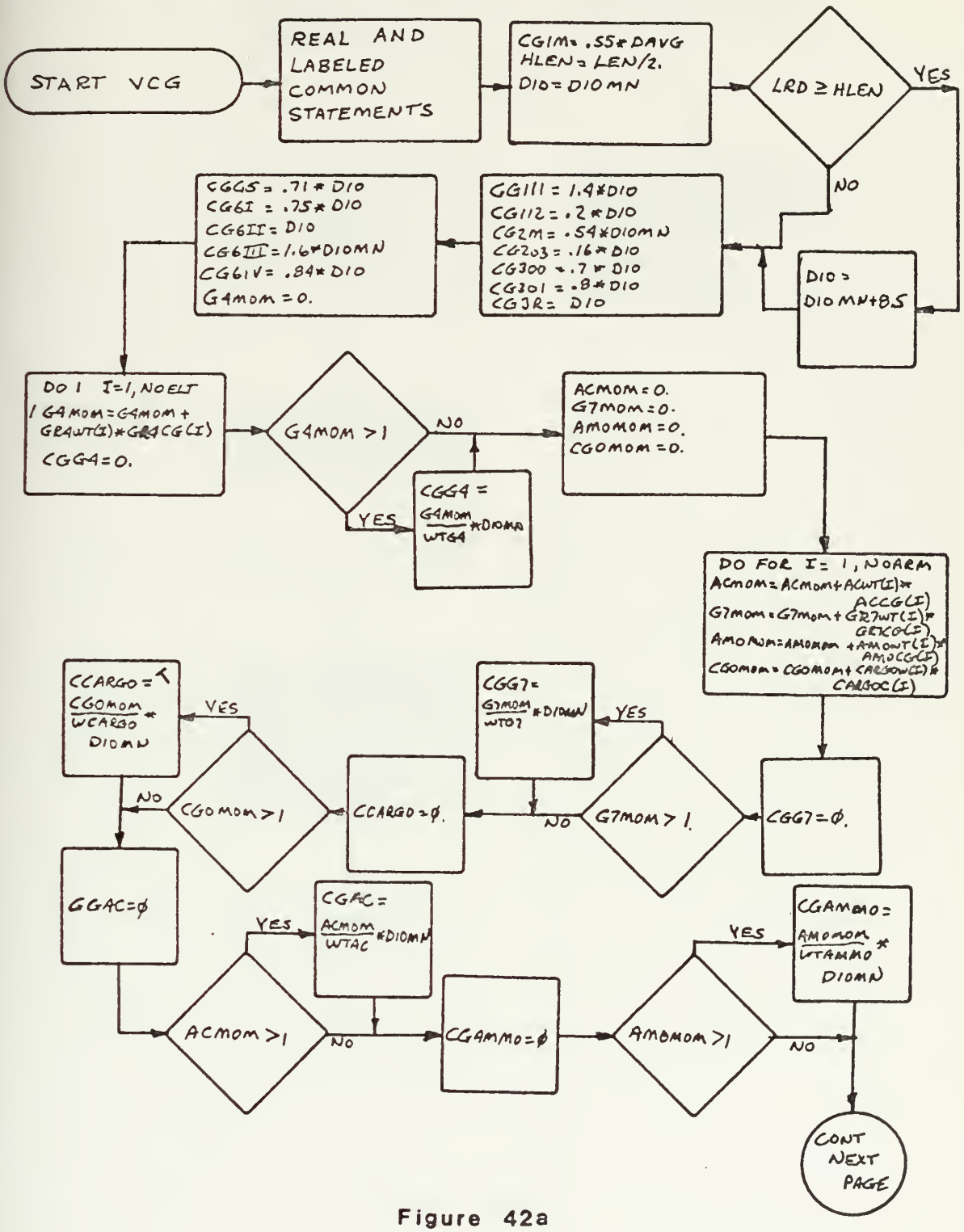



Figure 42a

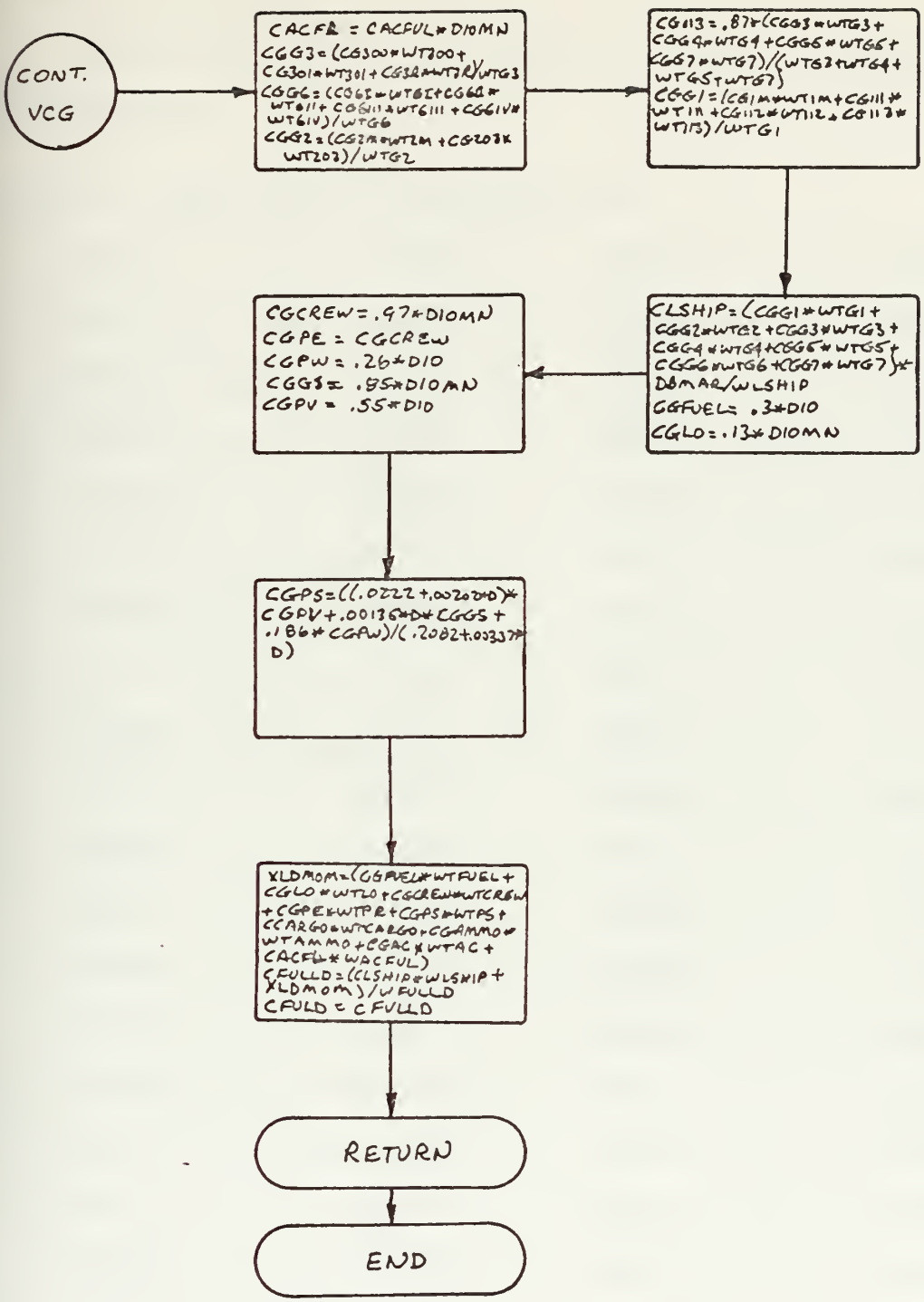

CONT.
VCG
CACFR = CACFUL*DIOMN
CGG3=(CG300*WT300+
CG301*WT301+CG3RAWT3R)/WTG3
CGG6=(CG6I*WT6I+CGG62*
WT611+CGG111*WT6111+CGG1V*
WT61V)/WTG6
CGG2=(CG2M*WT2M+CG203*
WT203)/WTG2
CG113=.87*(CGG3*WTG3+
CGG4*WTG4+CGG5*WTG5+
CGG7*WTG7)/(WTG3+WTG4+
WTG5+WTG7)
CGG1=(CG1M*WT1M+CG111*
WT11R+CG112*WT112+CG113*
WT113)/WTG1
CGCREW=.97*DIOMN
CGPE=CGCREW
CGPW=.26*DIO
CGGS=.85*DIOMN
CGPV=.55*DIO
CLSHIP=(CGG1*WTG1+
CGG2*WTG2+CGG3*WTG3+
CGG4*WTG4+CGG5*WTG5+
CGGG*WTG6+CGG7*WTG7)*
DOMAR/WLSHIP
CGFUEL=.3*DIO
CGLO=.13*DIOMN
CGPS=((.0222+.002000)*
CGPV+.00136*D*CGGS+
.186*CGPW)/(.2082+.03337*
D)
XLDMOM=(CGFUEL*WTFUEL+
CGLO*WTLO+CGCREW*WTCREW
+CGPE*WTPR+CGPS*WTPS+
CCARGO*WTCARGO+CGAMMO*
WTAMMO+CGAC*WTAC+
CACFL*WACFUL)
CFULLD=(CLSHIP*WLSHIP+
XLDMOM)/WFULLD
CFULD=CFULLD
RETURN
END

Figure 42b

input.

A flow chart for this routine is shown in Figures 42a and 42b.

3.13.2 Input List for Subroutine VCG

ACCG.....LC(EE)
ACWT.....LC(EE)
AMOCG.....LC(EE)
AMOWT.....LC(EE)
CACFUL.....LC(HH)
CARGOC.....LC(EE)
CARGOW.....LC(EE)
D.....LC(AA)
D10MN.....LC(II)
DAVG.....LC(BB)
DBMAR.....LC(WW)
GR4CG.....LC(EE)
GR4WT.....LC(EE)
GR7CG.....LC(EE)
GR7WT.....LC(EE)
LEN.....LC(BB)
LRD.....LC(JJ)
NOARM.....LC(FF)
NOELT.....LC(FF)
WACFUL.....LC(LL)
WCARGO.....LC(LL)
WFULLD.....LC(WW)
WT113.....LC(VV)
WT1M.....LC(VV)
WT203.....LC(VV)
WT2M.....LC(VV)
WT300.....LC(VV)
WT301.....LC(VV)
WT3R.....LC(VV)
WT6I.....LC(VV)
WT6II.....LC(VV)
WT6III.....LC(VV)
WT6IV.....LC(VV)
WTAMMO.....LC(LL)
WTCREW.....LC(LL)
WTFUEL.....LC(LL)
WTG1.....LC(WW)
WTG2.....LC(WW)
WTG3.....LC(WW)
WTG4.....LC(WW)
WTG5.....LC(WW)
WTG6.....LC(WW)
WTG7.....LC(WW)
WTLO.....LC(LL)

WLSHIP.....LC(WW)  WTPE.....LC(LL)

WT111.....LC(VV)  WTPS.....LC(LL)

WT112.....LC(VV)

3.13.3 Statement Descriptions

Detailed statement descriptions will not be given for this routine. In general the statements consist of vcg estimates using the relationships mentioned in the introduction or of calculations to combine weight groups by summing the vertical moments of individual groups and dividing by the total weight.

Note that D10 is different from D10MN only if the length of raised deck is greater than one half the ship length. It must also be remembered that input moment arms are given as fractions of the main deck depth at amidships and not as a distance in feet.

3.13.4 Output List for Subroutine VCG

CCARGO.....LC(OO)  CGG3.....LC(OO)

CFULD.....SCDA  CGG4.....LC(OO)

CFULLD.....LC(OO)  CGG5.....LC(OO)

CGAC.....LC(HH)  CGG6.....LC(OO)

CGAMMO.....LC(HH)  CGG7.....LC(OO)

CGCREW.....LC(HH)  CGLO.....LC(HH)

CGFUEL.....LC(HH)  CGPE.....LC(HH)

CGG1.....LC(OO)  CGPS.....LC(HH)

CGG2.....LC(OO)  CLSHIP.....LC(OO)

3.13.5 Nomenclature List

| | |
|---|---|
| ACMOM | total vertical aircraft moment, tons |
| AMOMOM | total vertical ammunition moment, tons |
| CACFL | vertical center aircraft fuel, ft |
| CFULD | same as CFULLD |
| CFULLD | vertical center of ship at full load, ft |
| CG111 | vertical center of group 111, ft |
| CG112 | vertical center of group 112, ft |
| CG113 | vertical center of group 113, ft |
| CG1M | vertical center of group 1M, ft |
| CG203 | vertical center of group 203, ft |
| CG2M | vertical center of group 2M, ft |
| CG300 | vertical center of group 300, ft |
| CG301 | vertical center of group 301, ft |
| CG3R | vertical center of group 3R, ft |
| CG6I | vertical center of group 6I, ft |
| CG6II | vertical center of group 6II, ft |
| CG6III | vertical center of group 6III, ft |
| CG6IV | vertical center of group 6IV, ft |
| CGG1 | vertical center of group 1, ft |
| CGG2 | vertical center of group 2, ft |
| CGG3 | vertical center of group 3, ft |
| CGG4 | vertical center of group 4, ft |
| CGG5 | vertical center of group 5, ft |
| CGG6 | vertical center of group 6, ft |
| CGG7 | vertical center of group 7, ft |
| CGGS | vertical center of general stores, ft |

| | |
|---|---|
| CGOMOM | vertical moment of cargo, tons |
| CGPV | vertical center of provisions, ft |
| CGPW | vertical center of potable water, ft |
| CLSHIP | vertical center of light ship, ft |
| CPO | same as NCPO in MAIN |
| D | same as ENDDAY in MAIN |
| D0 | depth at F.P., ft |
| D10 | depth amidships to main or raised deck, ft |
| D10MN | depth amidships to main deck, ft |
| D20 | depth at A.P., ft |
| ENL | same as NENL in MAIN |
| G4MOM | total group 4 moment, tons |
| G7MOM | total group 7 moment, tons |
| HLEN | half the length of the ship, ft |
| I | index |
| OFF | same as NOFF in MAIN |
| WT1M | weight group 1M, tons |
| WT111 | weight group 111, tons |
| WT112 | weight group 112, tons |
| WT113 | weight group 113, tons |
| WT203 | weight group 203, tons |
| WT2M | weight group 2M, tons |
| WT300 | weight group 300, tons |
| WT301 | weight group 301, tons |
| WT3R | weight group 3R, tons |
| WT6I | weight group 6I, tons |
| WT6II | weight group 6II, tons |

| | |
|---|---|
| WT6III | weight group 6III, tons |
| WT6IV | weight group 6IV, tons |
| XLDMOM | total load moment, ton-ft |

## 3.14 Subroutine COST

### 3.14.1 Introduction

This subroutine is based exclusively on the preliminary cost estimating procedure currently used by the Coast Guard. To use the procedure, the weight of each of the seven light ship weight groups must be known. Linear graphs for man hours and material cost are then entered with these values to determine the cost and labor required for each weight group.

Various relationships are also given for determining design costs, construction services cost and miscellaneous costs. Miscellaneous costs include initial outfit equipment such as lifejackets as well as retrofit costs, spare parts and administrative or resident inspector's office costs.

The curves used in the procedure were converted to formulas and the procedure was programmed as subroutine COST. A flow chart for this routine is given in Figure 43.

All of the material cost curves are based on 1959 prices. Indices are used to correct the prices to the year the ship will be built. These indices are based on Bureau of Labor Statistics data for the particular weight group.

The labor rate for all of the weight groups is assumed to be the same. The labor rate is inputed as an average dollars per hour for the year the ship will be built.

# COST SUBROUTINE FLOW CHART

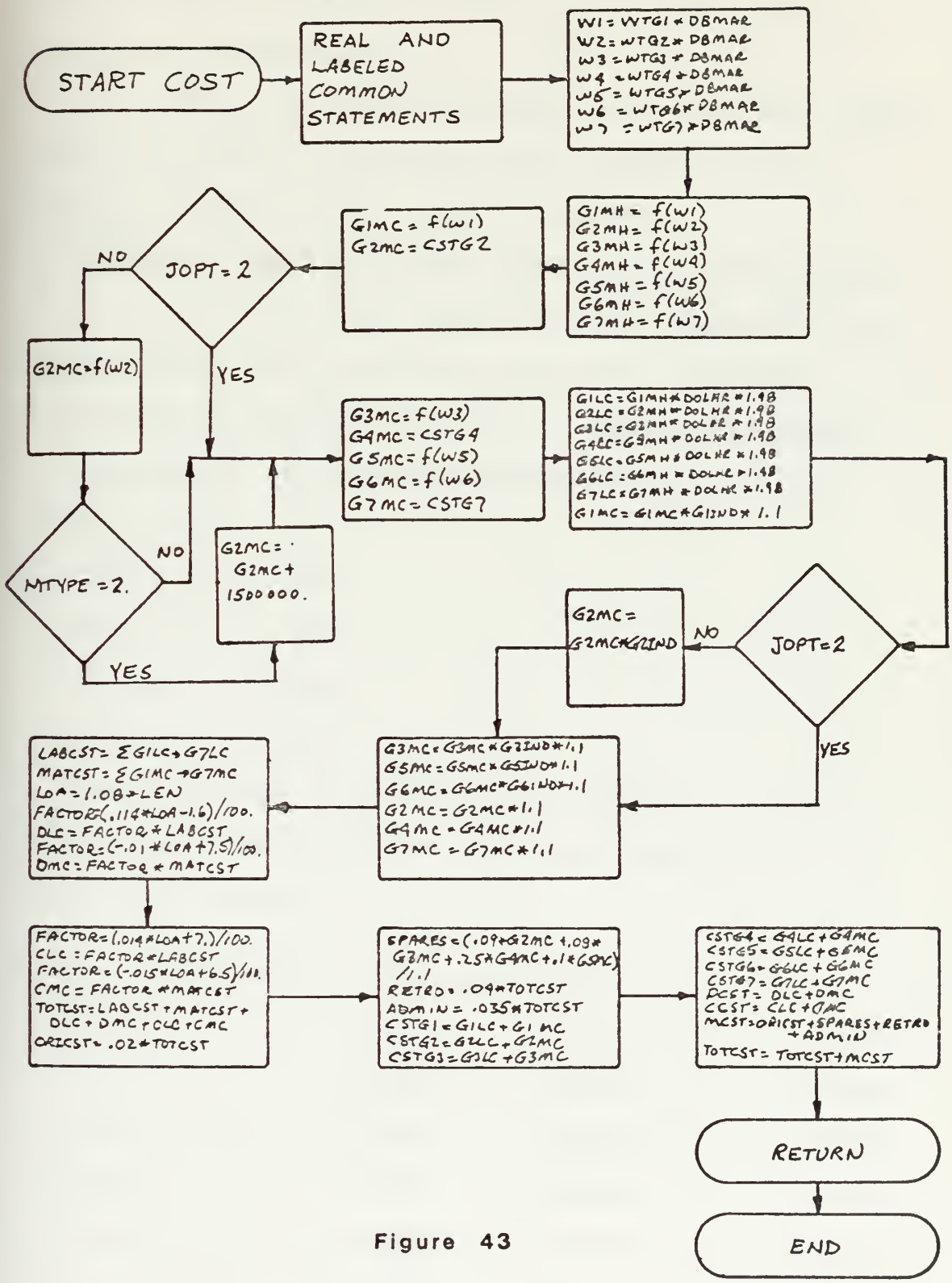

START COST
REAL AND LABELED COMMON STATEMENTS
W1 = WTG1 * DBMAR
W2 = WTG2 * DBMAR
W3 = WTG3 * DBMAR
W4 = WTG4 * DBMAR
W5 = WTG5 * DBMAR
W6 = WTG6 * DBMAR
W7 = WTG7 * DBMAR
G1MH = f(W1)
G2MH = f(W2)
G3MH = f(W3)
G4MH = f(W4)
G5MH = f(W5)
G6MH = f(W6)
G7MH = f(W7)
JOPT = 2
NO
YES
G1MC = f(W1)
G2MC = CSTG2
G2MC = f(W2)
G3MC = f(W3)
G4MC = CSTG4
G5MC = f(W5)
G6MC = f(W6)
G7MC = CSTG7
G1LC = G1MH * DOLHR * 1.98
G2LC = G2MH * DOLHR * 1.98
G3LC = G2MH * DOLHR * 1.98
G4LC = G3MH * DOLHR * 1.98
G5LC = G5MH * DOLHR * 1.98
G6LC = G6MH * DOLHR * 1.98
G7LC = G7MH * DOLHR * 1.98
G1MC = G1MC * G1IND * 1.1
MTYPE = 2.
NO
YES
G2MC = G2MC + 1500000.
G2MC = G2MC * G2IND
NO
JOPT = 2
YES
G3MC = G3MC * G2IND * 1.1
G5MC = G5MC * G5IND * 1.1
G6MC = G6MC * G6IND * 1.1
G2MC = G2MC * 1.1
G4MC = G4MC * 1.1
G7MC = G7MC * 1.1
LABCST = Σ G1LC → G7LC
MATCST = Σ G1MC → G7MC
LOA = 1.08 * LEN
FACTOR = (.114 * LOA - 1.6) / 100.
DLC = FACTOR * LABCST
FACTOR = (-.01 * LOA + 7.5) / 100.
DMC = FACTOR * MATCST
FACTOR = (.014 * LOA + 7.) / 100.
CLC = FACTOR * LABCST
FACTOR = (-.015 * LOA + 6.5) / 100.
CMC = FACTOR * MATCST
TOTCST = LABCST + MATCST + DLC + DMC + CLC + CMC
ORICST = .02 * TOTCST
SPARES = (.09 * G2MC + .09 * G3MC + .25 * G4MC + .1 * G5MC) / 1.1
RETRO = .04 * TOTCST
ADMIN = .035 * TOTCST
CSTG1 = G1LC + G1MC
CSTG2 = G2LC + G2MC
CSTG3 = G3LC + G3MC
CSTG4 = G4LC + G4MC
CSTG5 = G5LC + G5MC
CSTG6 = G6LC + G6MC
CSTG7 = G7LC + G7MC
DCST = DLC + DMC
CCST = CLC + CMC
MCST = ORICST + SPARES + RETRO + ADMIN
TOTCST = TOTCST + MCST
RETURN
END

Figure 43

Material cost indices and labor rate data are shown in Figures 44 and 45. There is a large fluctuation in costs between shipyards so these numbers can only be viewed as average values.

In addition to the corrections for inflation, eighty percent is added to labor cost for overhead and ten percent is added to all costs for profit.

Initial outfit costs are assumed to be two percent of the total cost. Spare parts cost is the sum of the cost of spares for propulsion machinery, electrical machinery, electronics and outfit. The cost of spares as a percentage of the weight group material cost is given below:

Group 2 --- 9%

Group 3 --- 8%

Group 4 --- 25%

Group 5 --- 10%

Retrofit cost is assumed to be 4 percent of the total cost. Administrative socts are assumed to be 3.5 percent of the total.

3.14.2 Input List for Subroutine COST

| | |
|---|---|
| CSTG2*.....LC(MM) | G1IND.....LC(NN) |
| CSTG4.....LC(MM) | G2IND.....LC(NN) |
| CSTG7.....LC(MM) | G3IND.....LC(NN) |
| DBMAR.....LC(WW) | G5IND.....LC(NN) |
| DOLHR.....LC(NN) | G6IND.....LC(NN) |

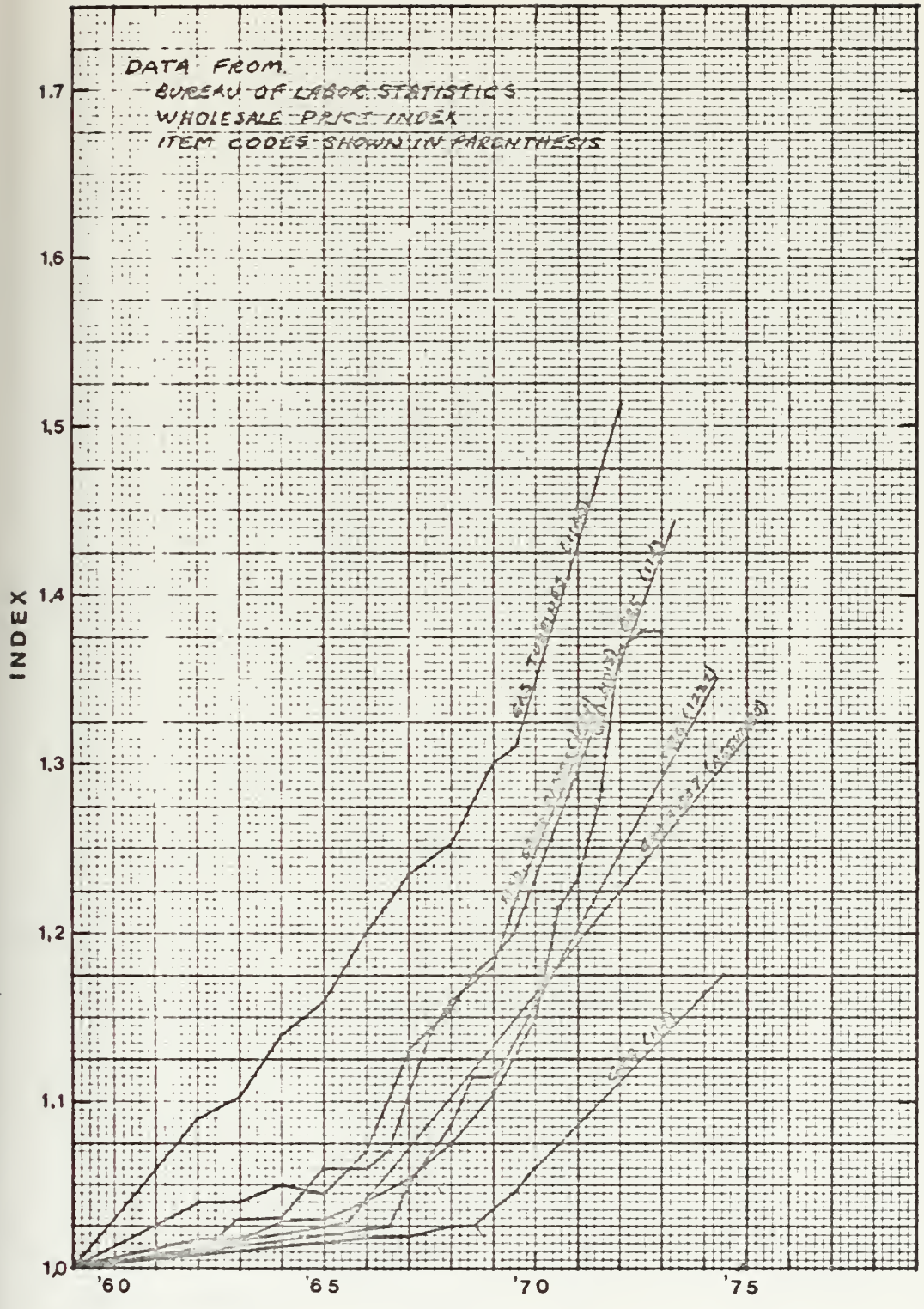

DATA FROM
BUREAU OF LABOR STATISTICS
WHOLESALE PRICE INDEX
ITEM CODES SHOWN IN PARENTHESIS
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
INDEX
'60
'65
'70
'75
YEAR

Figure 44

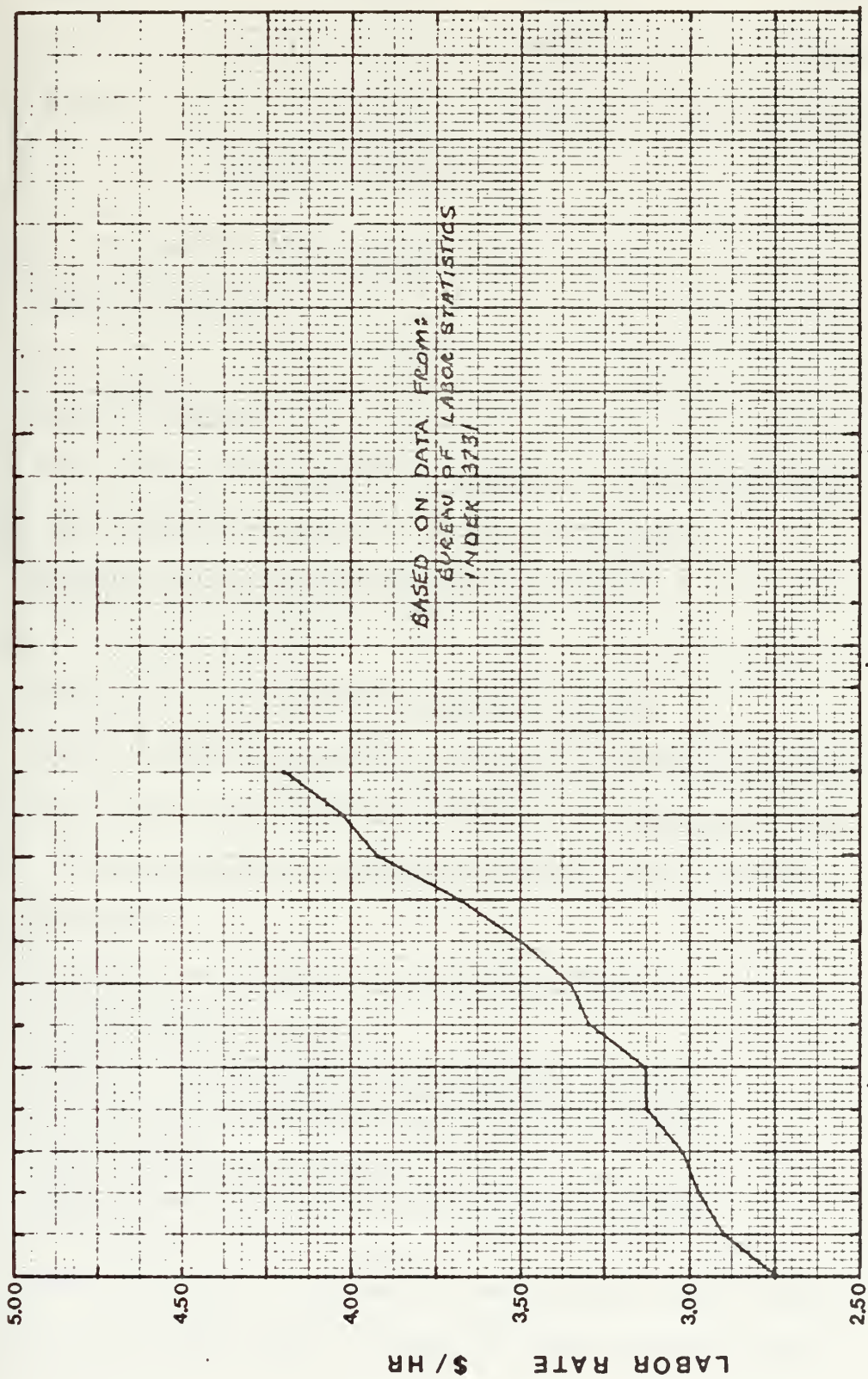

5.00
4.50
4.00
3.50
3.00
2.50
'60
'65
'70
'75
'80
LABOR RATE $/HR
YEAR
BASED ON DATA FROM:
BUREAU OF LABOR STATISTICS
UNDER 323

Figure 45

| | |
|---|---|
| JOPT.....LC(CC) | WTG3.....LC(WW) |
| LEN.....SCDA | WTG4.....LC(WW) |
| MTYPE.....LC(CC) | WTG5.....LC(WW) |
| WTG1.....LC(WW) | WTG6.....LC(WW) |
| WTG2.....LC(WW) | WTG7.....LC(WW) |

*only if JOPT = 2

3.14.3 Statement Descriptions

```
W1=WTG1*DBMAR
      .
      .
      .
W7=WTG7*DBMAR
```

The design and builders margin is evenly divided among the weight groups for costing purposes.

```
G1MH=10.**(ALOG10(W1)*.75217+2.97276)
      .
      .
      .
G7MH=10.**(ALOG10(W7)*.75217+2.97276)
```

These formulas represent the relationships between man-hours and the weight of individual weight groups. These relationships are assumed linear when plotted on log-log paper.

```
      G1MC=10.**(ALOG10(W1)*.954243+2.790484)
      G2MC=CSTG2
      IF(JOPT.EQ.2) GOTO 1
      G2MC=10.**(ALOG10(W2)*1.018885+3.634328)
      IF(MTYPE.EQ.2) G2MC=G2MC+1500000.
    1 G3MC=10.**(ALOG10(W3)*1.072551+3.667812)
      G4MC=CSTG4
      G5MC=10.**(ALOG10(W5)*.870906+3.974192)
      G6MC=10.**(ALOG10(W6)*1.068265+3.603833)
      G7MC=CSTG7
```

These formulas represent the material cost curves used by the Coast Guard. Some of these costs, CSTG2,

CSTG4 and CSTG7, are input. Group 2 cost is an input only if the machinery plant is specified. Otherwise, the machinery cost is calculated. The formula used represents the cost of diesel plants. An extra $1.5 million is added if a CODOG plant is to be installed.

```
G1LC=G1MH*DOLHR*1.98
        .
        .
        .
G7LC=G7MH*DOLHR*1.98
```

The labor cost by weight group is calculated here. The value, 1.98, represents an overhead factor of 1.8 times a profit factor of 1.1.

```
      G1MC=G1MC*G1IND*1.1
      IF(JOPT.EQ.2) GOTO 2
      G2MC=G2MC*G2IND
    2 G3MC=G3MC*G3IND*1.1
      G5MC=G5MC*G5IND*1.1
      G6MC=G6MC*G6IND*1.1
      G2MC=G2MC*1.1
      G4MC=G4MC*1.1
      G7MC=G7MC*1.1
```

In these formulas the material cost is corrected for inflation and a factor of 1.1 is included for profit. Note that the costs given as input are not corrected for inflation. Therefore, the cost of the equipment must be corrected for inflation before being inputed.

```
LABCST=G1LC+G2LC+G3LC+G4LC+G5LC+G6LC+G7LC
MATCST=G1MC+G2MC+G3MC+G4MC+G5MC+G6MC+G7MC
```

The total labor and material costs are calculated in these statements.

```
LOA=1.08*LEN
FACTOR=(.114*LOA-1,6)/100.
DLC=FACTOR*LABCST
FACTOR=(-.01*LOA+7.5)/100.
DMC=FACTOR*MATCST
```

These statements calculate the design labor, DLC, and design materials, DMC, costs for the first ship of a class from the beginning of the conceptual design stage. The two values of FACTOR are based on Coast Guard curves. Since the length overall is required in these curves, its value is estimated as eight percent greater than the length between perpendiculars.

```
FACTOR=(.014*LOA+7.)/100.
CLC=FACTOR*LABCST
FACTOR=(-.015*LOA+6.5)/100.
CMC=FACTOR*MATCST
```

The construction services labor and material costs are calculated here. Again the formulas for the two values of FACTOR are based on Coast Guard curves.

```
TOTCST=LABCST+MATCST+DLC+DMC+CLC+CMC
ORICST=.02*TOTCST
SPARES=(.09*G2MC+.08*G3MC+.25*G4MC+.1*G5MC)/1.1
RETRO=.04*TOTCST
ADMIN=.035*TOTCST
```

The four items that are included in the miscellaneous cost are calculated here. Since profit is included in the individual weight group material costs it is divided out when calculating the cost of spares.

```
CSTG1=G1LC+G1MC
      .
      .
      .
CSTG7=G7LC+G7MC
```

Total weight group costs are calculated here

```
DCST=DLC+DMC
CCST=CLC+CMC
MCST=ORICST+SPARES+RETRO+ADMIN
TOTCST=TOTCST+MCST
RETURN
END
```

Finally, the total design cost, construction services cost, miscellaneous cost and the total first ship cost are calculated.

3.14.4 Output List for Subroutine COST

| | |
|---|---|
| CCST.....LC(MM) | CSTG6.....LC(MM) |
| CSTG1.....LC(MM) | CSTG7.....LC(MM) |
| CSTG2*.....LC(MM) | DCST.....LC(MM) |
| CSTG3.....LC(MM) | MCST.....LC(MM) |
| CSTG4.....LC(MM) | TOTCST.....LC(NN) |
| CSTG5.....LC(MM) | |

* only if JOPT = 1

3.14.5 Nomenclature List

The definition of all variables is the same as that given in the MAIN program nomenclature except for the following:

| | |
|---|---|
| ADMIN | administrative costs, dollars |
| CLC | construction services labor cost, dollars |
| CMC | construction services material cost, dollars |
| DLC | design labor cost, dollars |
| DMC | design materials cost, dollars |
| FACTOR | see text |
| G1LC | weight group 1 labor cost, dollars |

| | |
|---|---|
| G2LC | weight group 2 labor cost, dollars |
| G3LC | weight group 3 labor cost, dollars |
| G4LC | weight group 4 labor cost, dollars |
| G5LC | weight group 5 labor cost, dollars |
| G6LC | weight group 6 labor cost, dollars |
| G7LC | weight group 7 labor cost, dollars |
| G1MC | weight group 1 material cost, dollars |
| G2MC | weight group 2 material cost, dollars |
| G3MC | weight group 3 material cost, dollars |
| G4MC | weight group 4 material cost, dollars |
| G5MC | weight group 5 material cost, dollars |
| G6MC | weight group 6 material cost, dollars |
| G7MC | weight group 7 material cost, dollars |
| G1MH | weight group 1 man-hours |
| G2MH | weight group 2 man-hours |
| G3MH | weight group 3 man-hours |
| G4MH | weight group 4 man-hours |
| G5MH | weight group 5 man-hours |
| G6MH | weight group 6 man-hours |
| G7MH | weight group 7 man-hours |
| LABCST | total construction labor cost, dollars |
| LOA | length overall, ft |
| MATCST | total construction material cost, dollars |
| ORICST | initial outfit cost, dollars |
| RE | same as RGEND in MAIN |
| RETRO | retrofit cost, dollars |
| SFCH | same as SFCHHP in MAIN |

| | |
|---|---|
| SFCM | same as SFCMHP in MAIN |
| SPARES | spare parts cost, dollars |
| VE | same as VEND in MAIN |
| W1 | weight group 1 with margin, tons |
| W2 | weight group 2 with margin, tons |
| W3 | weight group 3 with margin, tons |
| W4 | weight group 4 with margin, tons |
| W5 | weight group 5 with margin, tons |
| W6 | weight group 6 with margin, tons |
| W7 | weight group 7 with margin, tons. |

## 3.15 Subroutine SEASPD

### 3.15.1 Introduction

This routine is based on the work of Michael Shen, Peter Gale and Kenneth Walker as reported in References 4 and 5. In these references is given a computer program for computing the average sea speed. This computer program was altered by dropping the option to use a bow sonar dome and by deleting the read and write statements. The program was also rewritten in ASA standard FORTRAN. Except for these changes, subroutine SEASPD is the computer program developed by these three men. The interested reader is referred to these references for the development of the routine.

Briefly, the routine assumes: (1) that the ship is operating in the North Atlantic Ocean over a long period of time; (2) that it is steaming into head seas one half of the time; (3) that the remainder of the time (when steaming at other headings) it is not forced to reduce speed due to ship motions. Part of the time the ship is steaming into head seas, its speed will be limited be the sea state. In the routine this is simplified to a single sea state limited speed. The remainder of the time the ship is assumed to be able to make its maximum sustained speed. The percentage of the time the ship is limited in speed is estimated based on average wave heights in the North Atlantic Ocean and on ship characteristics.

The average speed at sea is calculated assuming that the vessel will travel at its maximum sustained speed whenever it is not limited in speed by the sea state. When the vessel is steaming at headings other than into head seas, its speed is not limited. This is assumed to be one half the time. When steaming into head seas its speed will be limited only part of the time. Both the limiting speed and the percentage of time that it applies are calculated in SEASPD.

This routine has been included to indicate the effect that changes in the vessels characteristics will have on its seakeeping ability. The many assumptions made in deriving the average sea speed make the speed predicted practically meaningless. However, the speed calculated can be used to compare two designs to decide which will give the better sea keeping performance.

A flow chart for this routine is shown in Figure 46.

3.15.2 Input List for Subroutine SEASPD

| | |
|---|---|
| B.....LC(GG) | DPTRY.....LC(GG) |
| CP.....LC(GG) | H.....LC(GG) |
| CWP.....LC(GG) | LEN.....LC(BB) |
| CX.....LC(GG) | VSUS.....LC(CC) |

3.15.3 Statement Descriptions

For a detailed discussion of this routine see References 4 and 5.

# SEASPD SUBROUTINE FLOW -CHART

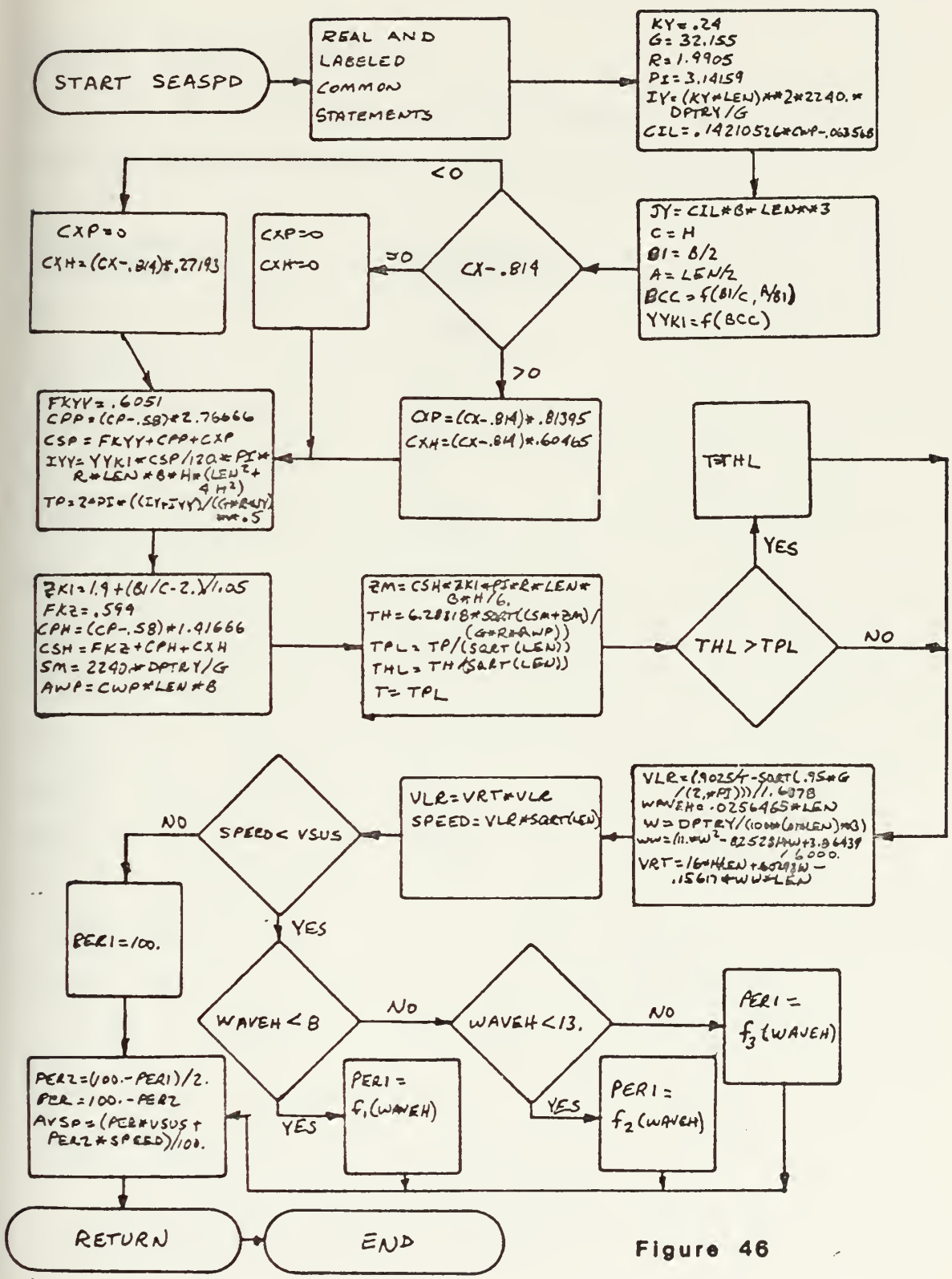



Figure 46

3.15.4 Output for Subroutine SEASPD

The only output is the value of average sea speed, AVSP.

3.15.5 Nomenclature List

The definitions used are the same as those given in References 4 and 5 except for the following:

| Value used in SEASPD | Value used in references |
|---|---|
| B | BEAM |
| LEN | SL |
| CWP | CW |
| B1 | B |
| DPTRY | DISPO |
| KY | DKY |
| IYY | YYI |
| JY | YJ |
| IY | YI |
| VSUS | VVV |
| VLR | VPX |

## 3.16 Subroutine OUTPUT

### 3.16.1 Introduction

All program output is printed by subroutine OUTPUT except for error messages. A simplified flow chart for this routine is shown in Figure 47. Subroutine OUTPUT is divided into two main parts. The first prints the input data and the second prints the output generated.

If an error message is printed, only part of the output data is available and the data that is available is probably not correct. Therefore, when an error message occurs, only the input data is printed. Variable I1 has a value of 1 in this case. If the program successfully completes all preceeding steps, I1 is assigned a value of 2 and output data is also printed.

Subroutine OUTPUT consists primarily of write and format statements. Some calculations are made but only to convert previously calculated values to a desired output form such as determining ratios between weight groups and full load weight.

Only two decision points are used. One is the decision on whether or not to print output. The other checks the option used for inputting vehicle performance data and chooses the correct set of write and format statements to print the input data.

### 3.16.2 Input for Subroutine OUTPUT

All values which are printed are inputs to this routine.

OUTPUT SUBROUTINE
FLOW CHART

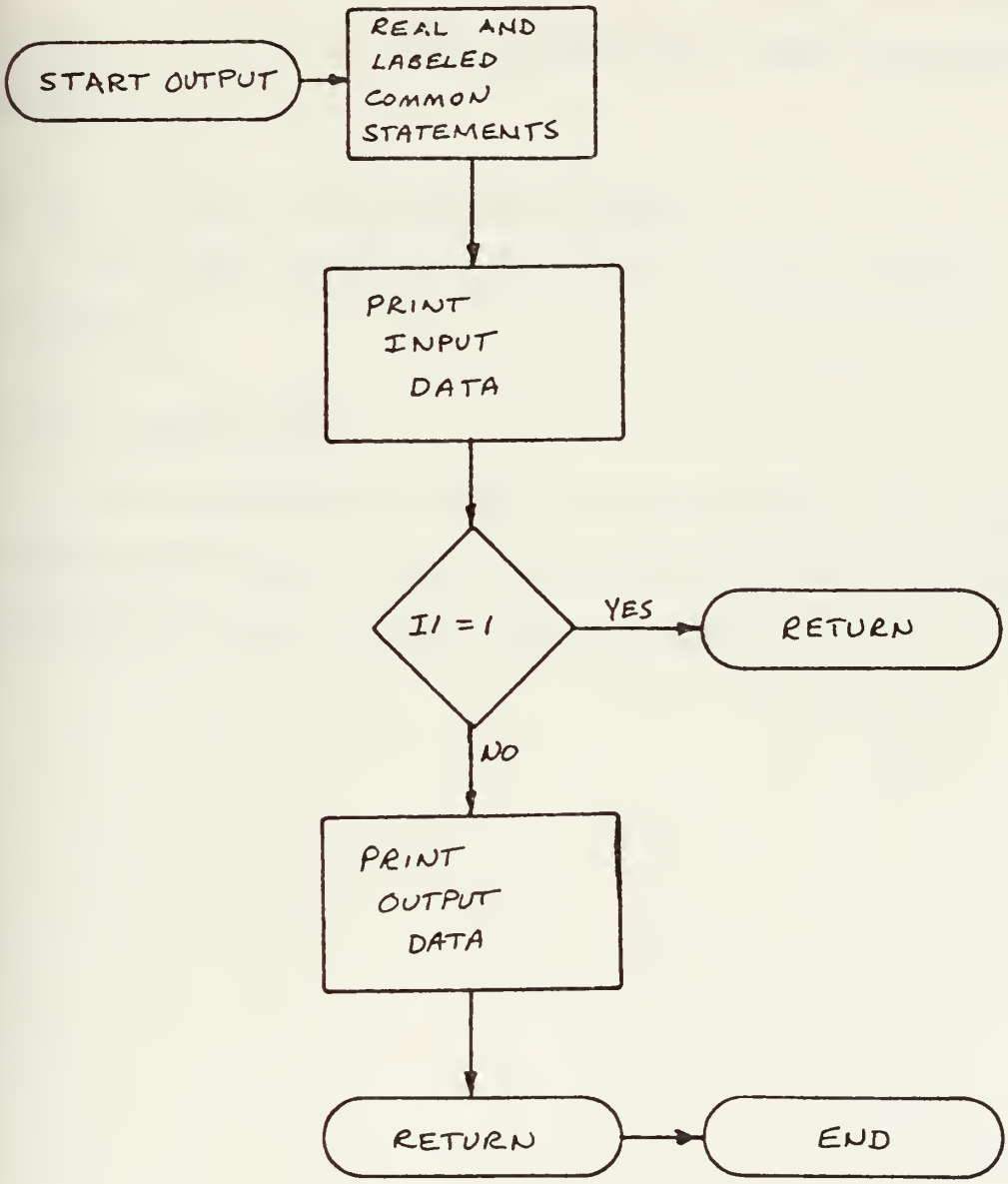



Figure 47

### 3.16.3 Statement Descriptions

Detailed descriptions of the statements of this routine will not be given since most of the statements are self-explanatory. Use of the sample outputs given in Appendix B will be of use in understanding the format statements used.

### 3.16.4 Output for Subroutine OUTPUT

No values are generated in this routine for use elsewhere.

### 3.16.5 Nomenclature

All the variables used in this routine have been defined previously except for some dummy variables whose definition should be clear from context.

## CHAPTER IV

## EVALUATION OF THE PROGRAM

A number of test runs were made on an IBM 370, model 168, computer located in the Information Processing Center at M.I.T. The test runs were made using input data for four existing designs, the 378' WHEC, the 210' WMEC, the 150' WPB, and the Navy's Patrol Frigate design. The Cutter Model produces feasible designs for each of these ships except the 150' WPB.

The design for the 150' WPB failed because a raised deck length greater than the ship length was required. The actual ship does not have a raised deck. The probable cause of this failure lies with the available area and volume relations used in the program. These relations were developed for ships with lengths greater than 400 feet and probably have significant errors when extended to ships as short as 150 feet. Recommendations for correcting this error are given in Chapter V.

A comparison between the results produced by the Cutter Model and the actual ships are shown in Tables 6a and 6b for the 378' WHEC and in Tables 7a and 7b for the 210' WMEC. The differences are reasonably small in most areas; however, a few do need discussion.

The largest difference with both ships occurs in

Table 6a

Comparison of Cutter Model Output to the Actual Ship for a 378' WHEC

| | $L_{bp}$ ft | Beam ft | Draft ft | D0 ft | D10 ft | D20 ft | Davg ft | Disp. tons |
|---|---|---|---|---|---|---|---|---|
| Ship | 350. | 42.0 | 14.3 | 34.75 | 27.25 | 27.5 | 28.54 | 2968.0 |
| Model | 350. | 43.32 | 14.6 | 38.33 | 27.83 | 28.18 | 29.64 | 3061.5 |

| | WEIGHTS | | VCG | |
|---|---|---|---|---|
| | Ship | Model | Ship | Model |
| WTG1 | 917.46 | 962.8 | 19.12 | 19.42 |
| WTG2 | 383.6 | 383.6 | 11.45 | 11.52 |
| WTG3 | 88.12 | 164.8 | 23.49 | 21.76 |
| WTG4 | 80.2 | 80.2 | 31.56 | 32.52 |
| WTG5 | 268.8 | 262.3 | 19.43 | 19.76 |
| WTG6 | 325.1 | 322.3 | 25.63 | 25.88 |
| WTG7 | 39.0 | 39.0 | 35.26 | 36.30 |
| WTLSHIP | 2102.2 | 2215.0 | 19.72 | 19.98 |
| FUEL | 661.8 | 653.2 | 7.67 | 8.35 |
| LUB OIL | 13.7 | 16.0 | 3.58 | 3.62 |
| CREW | } 22.03 | 13.7 | } 26.26 | 27.00 |
| PER EFFECTS | | 7.8 | | 27.00 |
| PER STORES | 107.4 | 95.1 | 11.35 | 14.36 |
| CARGO | 0. | 0. | | |
| AMMO | 37.5 | 37.5 | 15.99 | 16.42 |
| AIRCRAFT | 3.4 | 3.4 | 39.01 | 40.08 |
| A/C FUEL | 19.6 | 19.6 | 9.56 | 9.74 |
| WTFLLD | 2967.6 | 3061.4 | 16.61 | 17.20 |

Table 6b

Comparison of Cutter Model Output to the Actual Ship for a 378' WHEC

| | Ship | Model | |
|---|---|---|---|
| Hull Volume | 277600 | 273734 | cu ft |
| Deckhouse Volume | 95611 | 94705 | cu ft |
| Total Arrangements Area | 30863 | 29664 | sq ft |
| Hull Arrangements Area | 19615 | 18522 | sq ft |
| Deckhouse Arrangements Area | 11248 | 11142 | sq ft |
| Office Space | 493 | 510 | sq ft |
| Messing Facilities | 2713 | 2713 | sq ft |
| Crew Special | 725 | 787 | sq ft |
| Officer S.R. | 1157 | 1168 | sq ft |
| Officer Sanitary | 243 | 192 | sq ft |
| CPO S.R. | 1040 | 1040 | sq ft |
| CPO Sanitary | 250 | 208 | sq ft |
| Crew Berthing | 3641 | 3168 | sq ft |
| Crew Sanitary | 716 | 720 | sq ft |
| CO S.R., Cabin & Pantry | 755 | 753 | sq ft |
| Commissary Stores | 600 | 652 | sq ft |
| Other Stores | 3015 | 3231 | sq ft |
| Workshops | 1161 | 1254 | sq ft |
| Repair Lockers | 148 | 100 | sq ft |
| Chain Lockers | 47 | 40 | sq ft |
| Uptakes | 462 | 0* | sq ft |
| Steering Gear & Windlass | 736 | 779 | sq ft |
| A/C & Fan Spaces | 369 | 396 | sq ft |
| I.C. Spaces | 312 | 312 | sq ft |
| Aux. Machinery Spaces | 1860 | 2180 | sq ft |
| Pilot house, Chartroom & CIC | 1125 | 1111 | sq ft |
| Passages | 2567 | 2450 | sq ft |
| Input Area | 5283** | 5900 | sq ft |
| Excess Area | 1445 | 0 | |

* 460 sq ft included in input area

** Excess area was used for crew rec. rooms

Table 7a

Comparison of Cutter Model Output to the Actual Ship for a 210' WMEC

| | $L_{bp}$ ft | Beam ft | Draft ft | D0 ft | D10 ft | D20 ft | Davg ft | Disp. tons |
|---|---|---|---|---|---|---|---|---|
| Ship | 200. | 34.00 | 10.5 | 20.75 | 19.50 | 20.90 | 26.91 | 990.0 |
| Model | 200. | 35.02 | 8.98 | 21.50 | 19.50 | 19.70 | 24.97 | 959.1 |

| | WEIGHTS | | VCG | |
|---|---|---|---|---|
| | Ship | Model | Ship | Model |
| WTG1 | 379.5 | 347.8 | 16.4 | 13.92 |
| WTG2 | 102.6 | 102.6 | 9.5 | 9.55 |
| WTG3 | 43.7 | 75.4 | 17.5 | 22.28 |
| WTG4 | 26.1 | 26.1 | 34.2 | 33.31 |
| WTG5 | 110.4 | 109.6 | 16.6 | 19.88 |
| WTG6 | 104.4 | 106.8 | 22.6 | 25.93 |
| WTG7 | 8.5 | 8.5 | 23.4 | 23.21 |
| WTLSHIP | 775.2 | 776.8 | 17.1 | 17.40 |
| FUEL | 152.3 | 137.3 | 8.17 | 8.40 |
| LUB OIL | 3.8 | 3.9 | 2.5 | 2.54 |
| CREW | } 8.6 | 5.5 | 20.43 | 18.92 |
| PER EFFECTS | | 3.2 | 20.43 | 18.92 |
| PER STORES | 47.3 | 30.4 | 10.99 | 11.95 |
| CARGO | 0. | 0. | | |
| AMMO | 2.6 | 2.6 | 8.4 | 8.00 |
| AIRCRAFT | 0. | 0. | | |
| A/C FUEL | 0. | 0. | | |
| WTFLLD | 990.0 | 959.5 | 15.38 | 15.87 |

| | Ship | Model |
|---|---|---|
| Raised Deck Length | 164. | 120. |

Table 7b

Comparison of Cutter Model Output to the Actual Ship for a 210' WMEC

| | Ship | Model | |
|---|---|---|---|
| Hull Volume | 124700 | 123049 | cu ft |
| Deckhouse Volume | 16100 | 17840 | cu ft |
| Total Arrangements Area | 11242 | 11021 | sq ft |
| Hull Arrangements Area | 9345 | 8922 | sq ft |
| Deckhouse Arrangements Area | 1897 | 2099 | sq ft |
| Office Space | 130 | 192 | sq ft |
| Messing Facilities | 1452 | 1381 | sq ft |
| Crew Special | 324 | 313 | sq ft |
| Officer S.R. | 567 | 657 | sq ft |
| Officer Sanitary | 193 | 108 | sq ft |
| CPO S.R. | 283 | 320 | sq ft |
| CPO Sanitary | 75 | 64 | sq ft |
| Crew Berthing | 1658 | 1254 | sq ft |
| Crew Sanitary | 384 | 285 | sq ft |
| CO S.R., Cabin & Pantry | 406 | 398 | sq ft |
| Commissary Stores | 480 | 393 | sq ft |
| Other Stores | 1294 | 1233 | sq ft |
| Workshops | 544 | 382 | sq ft |
| Repair Lockers | 110 | 100 | sq ft |
| Chain Lockers | 42 | 40 | sq ft |
| Uptakes | 0 | 0 | |
| Steering Gear & Windlass | 270 | 390 | sq ft |
| A/C & Fan Spaces | 165 | 151 | sq ft |
| I.C. Spaces | 180 | 180 | sq ft |
| Aux. Machinery Spaces | 820 | 832 | sq ft |
| Pilot house, Chartroom & CIC | 422 | 486 | sq ft |
| Passages | 739 | 910 | sq ft |
| Input Area | 704 | 704 | sq ft |
| Excess Area | 0 | 247 | sq ft |

weight group 3, electric plant. This difference results from the fact that greater generating capacity relative to the average load has been built into the model than is installed in existing ships. This increase in generating capacity reflects current Coast Guard policy for new designs and is not an error in the program.

The differences in weight group 1 reflect the fact that the hull dimensions are not exactly the same for the program designs and the actual ships. Weight group 1 is a function primarily of the hull cubic number.

The fuel weight is calculated in the program based on specific fuel consumption, endurance range and endurance speed. An attempt has been made to approximate the actual fuel weight by varying one or more of these quantities but an exact match is difficult to obtain.

The only other significant weight difference occurs in personnel stores which includes potable water. The model results are less than the weights for the actual ships due to the fact that the amount of potable water per man has been reduced from the amount used on past designs. This is in accordance with current Coast Guard policy for future designs.

The vertical centers of gravity show quite a bit of variation when compared to the actual ships. However, the values in the program are only average values and will in general not agree with the values for any one ship.

In the case of the 210' WMEC, a raised deck is required. The model predicted a raised deck length 44 feet shorter than that of the actual ship. This is another indication that the available area and volume relations are inaccurate for smaller ships.

Hull areas are given in Tables 6b and 7b. The areas used in the cutter model for berthing and sanitary spaces are based on current minimum Coast Guard standards. These areas in general are lower than the areas on current ships.

Several runs were also made using data for the Navy's Patrol Frigate design. At the same time, runs were made on the Navy's destroyer model, DD07, using similar data. The results of these runs are shown in Tables 8 and 9.

The Patrol Frigate design is of interest because it is at the lower limit of applicability for the destroyer model and at the upper limit of applicability for the cutter model. Agreement between the values calculated by the two models and the actual ship as shown in Table 8, is reasonably good. Again, the group 3 weight is highest for the cutter model because 3 - 2000 KW generators are used instead of the 3 - 1000 KW generators on the actual ship. Also, it appears that the greater emphasis placed on habitability by the Coast Guard is reflected in a greater group 6 weight.

Table 9 gives the displacements predicted for greater lengths than the actual ship length. As the ship length

Table 8

Comparison of Cutter Model Output to the Actual Ship and to DD07 Estimate for the Patrol Frigate Design

| | $L_{bp}$ ft | Beam ft | Draft ft | D0 ft | D10 ft | D20 ft | Davg ft | Disp. tons |
|---|---|---|---|---|---|---|---|---|
| Ship | 408. | 45.0 | 14.5 | | | | | 3517. |
| Model | 405. | 45.95 | 15.34 | 41.07 | 28.92 | 29.33 | 31.01 | 3706.1 |
| DD07 | 405. | 46.72 | 15.3 | 41.00 | 33.99 | 34.80 | 35.30 | 3766.3 |

WEIGHTS

| | Ship | Model | DD07 |
|---|---|---|---|
| WTG1 | 1222.36 | 1199.6 | 1331.2 |
| WTG2 | 256.1 | 258.0 | 240.0 |
| WTG3 | 155.36 | 211.2 | 156.6 |
| WTG4 | 92.58 | 70.7 | 70.7 |
| WTG5 | 351.3 | 317.5 | 381.3 |
| WTG6 | 268.82 | 333.8 | 238.0 |
| WTG7 | 95.68 | 85.7 | 85.7 |
| WTLSHIP | 2442.20 | 2637.4 | 2666.3 |
| FUEL | 830.0 | 818.7 | 845.3 |
| LUB OIL | 20.22 | 20.2 | 0.6 |
| CREW & PE | 20.96 | 20.9 | 20.9 |
| PER STORES | 68.05 | 66.6 | 84.0 |
| CARGO | 67.0 | 75.0 | 80.9 |
| AMMO | 58.8 | 58.8 | 58.8 |
| AIRCRAFT | 10.0 | 10.0 | 10.0 |
| A/C FUEL | 0. | 0. | 0. |
| WTFLLD | 3517. | 3707.7 | 3766.9 |

Table 9

PATROL FRIGATE

Full Load Displacement vs. Length Estimates

| $L_{bp}$ | Displacement | |
|---|---|---|
| | DD07 | Cutter Model |
| 405. | 3766.3 | 3707.7 |
| 415. | 3652.2 | 3679.5 |
| 425. | 3537.1 | 3672.0 |
| 435. | 3401.6 | 3696.0 |
| 445. | 3458.8 | 3764.1 |
| 455. | 3529.2 | 3874.7 |
| 465. | 3640.5 | 3985.9 |

is increased, the displacements predicted by the cutter model begin to diverge from those predicted by DD07. This indicates that the cutter model begins to lose accuracy for ship lengths above 400 feet, the assumed upper limit of the cutter model. Table 9 also shows that the two models predict different optimums. This is a result of the assumptions built into the two models.

will require [illegible]

minimum, the [illegible]

# CHAPTER V

## RECOMMENDATIONS AND CONCLUSIONS

For the 378' WHEC and 210' WMEC, the full load displacements predicted by the cutter model are within four percent of the actual full load displacements of these two vessels. This is better accuracy than is obtainable with other currently available models for the size range of Coast Guard vessels. However, only a limited number of designs were used to develop the cutter model and these same designs were used to check it. The program should be used with caution until other designs are available to confirm the relationships used in the model.

Although the cutter model appears to give accurate results in its current form, there are several areas where significant improvements could be made. The two most important improvements are: (1) development of available arrangement area and volume relationships which are more applicable to ships of the size range used in the model and (2) expansion of the $C_r$ array used in calculating horsepower requirements. The electrical generator sizing criteria should also be given careful consideration to determine if the sizes which result are what is really desired.

The development of area and volume relationships

will require considerable developmental work. As a minimum, the variation of area with hull depth, beam, $C_p$, $C_x$, tankage volume, and machinery box length must be considered. A computer program should be developed to calculate tankage volume and arrangements area for systematic changes in these variables. The results could then be converted into formulas for use in the cutter model.

The expansion of the $C_r$ array could probably best be accomplished by fairing data from another model test series, such as series 64, into the data from Taylor's Standard Series. Where necessary some data may have to be assumed that is not available. An expansion of the array to speed length ratios of 3.0 and $C_v$ values up to 0.008 would be very desirable. With the current array limits, many ships can not be run which may be very desirable. Also, if the sustained horsepower is given as an input, there are many times when the array limits are exceeded during an iteration even though the final speed value may be well within the limits of the array.

Finally, the generator capacity predicted by the model appears to be excessive. This criteria should be given careful consideration. Existing 378' WHEC cutters seldom exceed the capacity of one 500 KW generator in normal steaming; however, the criteria built into the cutter model would result in 1500 KW generator sets being

installed.

Some general recommendations on the use of the model are also in order. First, a ship synthesis model is only a design tool. Complete reliance should never be placed on a model; but, if checked by hand calculations, the model will greatly inhance the engineer's ship design capability. Also, as a tool, the model must be kept current. This implies that periodic reviews must be made of the empirical relations used to insure that they are in agreement with current policy. Every new design built should also be plotted on the curves included in Chapter III as additional data. Changes should be made if the new data is not in agreement with the old.

It is expected that the model will most often be used for designing new ships. Studied most often will probably be changes in length and $C_p$. These values have been arranged so that this can be done by changing only one input card. However, changes in any of the input variables can be investigated.

If the model is used to investigate the sensitivity to changes in the design assumptions, it will be necessary to change statements in the program itself. If many of these studies are being performed, some of the fixed values in the program could be read in on input cards.

One constraint on all ship synthesis models is that variations in hull form can not be investigated. If hull forms much different from those of current designs are

desired, a new model has to be developed. It must be remembered that a ship synthesis model is really a multi-dimensional linearization of a complex problem. If large departures are made from the data base designs, the errors will increase in magnitude.

Finally, the cutter model could be programmed as part of a ship optimization routine, but it is recommended that this not be done. Such a procedure puts the designer out of a controlling position while putting total reliance on an optimization criteria. Optimization criteria are difficult to define if more than just the cost of the vessel is in question. It is felt that such questions as the balance between payload and cost are best left to the designer and not to a rigid formula.

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# APPENDIX A

# DESCRIPTION OF INPUT

# APPENDIX A

## Description of Input

Input for the cutter model can be divided into two main groups. The first group contains the data for the $C_r$ arrays used in estimating propulsion power. The second group contains the data for individual ships that are run.

Data for the $C_r$ arrays is read only once regardless of how many test cases are run. This data precedes all other data and the values never change. The $C_r$ array data can be stored on tape or disk if desired. A list of the values used is given in Appendix D.

The second group of data allows the user to specify the payload and performance as well as various other parameters of the ship the computer is to design. In order for the computer to produce reliable results, the input data must be the best that it is possible to specify. Past designs are a good starting point for determining reasonable input values.

The minimum number of data cards for the second group of input is 14. These cards are described below. Where more than one card may be used this fact is noted.

Card 1 -- A single number is entered on this card in card column 1. The values that can be used are:

0 - the program will stop

1 - this is the normal value to use

2 - a fine hull form will be assumed for the first iteration, $C_v$ = .0025.

Card 2 -- This card contains a heading that is printed above the output. All 80 columns can be used for any alphanumeric description desired.

Card 3 -- A single value is entered in card column 2. The total number of armament, aircraft and cargo payload data cards should be entered. A maximum of 20 can be used.

Card 4 -- This is really a set of cards containing the armament, aircraft and cargo payload data. The number of cards used is specified on card 3. Each of these cards has the following format: (All data should contain a decimal point)

columns 1--20 Any alphanumeric title describing the remainder of the data on the card.

columns 21-25 Cargo weight, enter the weight in tons.

columns 26-30 Cargo vcg, enter the ratio of cargo vcg divided by the depth of the ship at amidships.

columns 31-35 Group 7 weight, enter weight in tons.

columns 36-40 Group 7 vcg, enter ratio of kg to depth at amidships.

columns 41-45 Ammunition weight, enter weight in tons.

columns 46-50 Ammunition vcg, enter ratio of kg to depth at amidships.

columns 51-55 Aircraft weight, enter weight in tons.

columns 56-60 Aircraft vcg, enter ratio of kg to depth at amidships.

columns 61-65 Electrical load, enter value in KW.

columns 66-70 Deckhouse Area, enter area required to be in deckhouse in sq. ft.

columns 71-75 Hull Area, enter all remaining required area in sq. ft.

columns 76-80 Group 7 cost, enter acquisition cost in thousands of dollars.

Except for the moment arms, the values given on these cards are summed by category and only this sum is used in calculations. Therefore it does not matter whether all the data is given on one card or on several. The only requirement is that the vcg values apply to the weights which immediately precede them. All values which are included in light ship weight group 7 must be given as data on these cards.

If there is no payload data, card 3 should

contain a 1 and a blank card should be included for card 4.

Card 5 -- A single value is entered in card column 2. This is a count of the number of data cards described under card 6. A maximum of 20 can be used.

Card 6 -- This is really a set of electronics input data cards up to a maximum of 20. The number of cards is specified by card 5. Each of these cards has the following format: (All data should contain a decimal point)

columns 1--20 Any alphanumeric title describing the remainder of the data on the card.

columns 21-25 Group 4 weight, enter weight in tons.

columns 26-30 Group 4 vcg, enter ratio of kg to depth at amidships.

columns 31-35 Electrical load in KW.

columns 36-40 Deckhouse area, enter area required to be in deckhouse in sq. ft.

columns 41-45 Hull area, enter remaining required area in sq. ft.

columns 46-50 Group 4 cost, enter acquisition cost in thousands of dollars.

Again the data may be broken up in any way desired as long as the correct sets of

weight and vcg are given. On all of these cards and on the cards described under card 4, the area given under deckhouse area should included only the area that is required to be in the deckhouse. If an area can be either in the deckhouse or in the hull, it should be listed under hull area.

All items included in light ship weight group 4 must be entered on these cards. This includes standard navigation equipment. If there is no electronics data, card 5 should contain a 1 and a blank card should be included for card 6.

Card 7 -- The number of officers, CPOs and crew members are specified on this card. All numbers must be right-justified integers.

columns 1---5 number of officers

columns 6--10 number of chief petty officers

columns 11-15 number of enlisted men

Card 8 -- This card contains cost indices input. All values should contain a decimal point.

columns 1---5 labor rate in dollars/hour

columns 6--10 group 1 index

columns 11-15 group 2 index

columns 16-20 group 3 index

columns 21-25 group 5 index

columns 26-30 group 6 index

The values of the labor rate and cost indices may be found under Section 3.14, Figures and .

Card 9 -- The number of endurance days for dry provisions and aircraft fuel payload are given on this card. All values should contain a decimal point.

columns 1---5 endurance days for dry provisions

columns 6--10 weight of aircraft fuel, tons

columns 11-15 vcg of aircraft fuel, enter the ratio of kg to depth at amidships.

Card 10 -- A single value is entered in card column 2. Two options are available. If a 1 is entered, use card 11a. This option allows the user to input sustained speed and have the computer calculate horsepower. If a 2 is entered use card 11 b. Here particulars of the machinery plant are input and the sustained speed is calculated. Any other value will have an unknown effect.

Card 11a -- Use this card type if a value of 1 is entered on card 10. The maximum sustained speed, endurance speed and range and propulsive coefficients at endurance speed and maximum speed are entered on this card. All data should contain a decimal point.

columns 1---5 sustained speed in knots
columns 6--10 endurance speed in knots
columns 11-20 endurance range, nautical miles
columns 21-25 propulsive coef. at endurance speed
columns 26-30 propulsive coef. at maximum speed.

Card 11b -- Use this card type if a value of 2 is entered on card 10. The particulars of a specific machinery plant are entered on this card. All data should contain a decimal point.

columns 1---5 maximum sustained horsepower, enter as HP/1000
columns 6--10 minimum machinery box depth in feet
columns 11-15 machinery box length in feet
columns 16-20 total weight of group 2, tons
columns 21-25 specific fuel consumption at max. horsepower in lbs/HP-hr
columns 26-30 specific fuel consumption at half power in lbs/HP-hr
columns 31-35 endurance speed in knots
columns 36-45 endurance range, nautical miles
columns 46-50 propulsion auxiliaries electrical load in KW
columns 51-55 propulsive coef. at endurance speed

columns 56-60 propulsive coef. at maximum speed

columns 61-65 acquisition cost of group 2, thousands of dollars

columns 66-70 lub oil weight in tons.

Card 12 -- This card contains various input options and dimensions. All values except the first should contain a decimal point.

columns 1---5 MTYPE, a right-justified integer is entered here.

If MTYPE = 0 the program returns to read a new card 1

If MTYPE = 1 a diesel plant is assumed if the machinery particulars have not been given

If MTYPE = 2 a CODOG plant is assumed

If card 10 contains a value of 2, any value of MTYPE except 0 may be used.

columns 6--10 free surface correction, enter value in feet. This doesnot have to be a positive number. A negative number can be interpreted as a KG below the average built into the program.

columns 11-15 length between perpendiculars, enter the ships length in feet.

columns 16-20 $C_p$, enter a value for prismatic coefficient

columns 21-25 $C_x$, enter a value for mid-ship section coefficient

columns 26-30 GM/Beam, a value of 0.1 is commonly used

columns 31-35 design and builders margin, enter a value as a decimal, i.e. a 10% margin is entered as 0.1

columns 36-45 $\Delta C_f$, this is the frictional resistance correction used in horse-power calculations. A value of 0.0004 is commonly used.

Card 12 may be repeated as many times as desired with new data each time. Each new card is interpreted as a new data case.

Card 13 -- If it is desired to input an entirely new set of payload and performance data or to stop, a value of 0 should be given in column 5 of card 12. This will cause a new card 1 to be read.

Card 14 -- A new card 1 must be included. If new data will be given all of the data cards must be repeated. A value of 0 on card 1 will cause the program to stop.

A sample listing of the group 2 data cards is given below. The data used refers to a 210' WMEC.

Card 1

1

Card 2

210 WMEC TEST RUN

Card 3

5

Card 4

```
Group 700                4.7 1.64                          385.  76.
Group 701                 .6 1.01
Group 702                2.8  .60
Group 750                 .4  .31
Ammunition                        2.56  .41
                          .    .    .    .                .    .
            columns      35   40   45   50                75   80
```

Card 5

6

Card 6

```
Group 400        .7 1.8521.99 319.       190.
Group 401       2.4 1.3
Group 402        .2 1.56
Group 403      10.4  .92
Group 404       9.1 2.69
Group 450       3.3 1.76
                  .    .    .    .         .
      columns    25   30   35   40        50
```

Card 7

```
    9    8   57
    .    .    .
    5   10   15 - columns
```

Card 8

```
 4.75  1.4  1.6 1.19 1.55 1.39
    .    .    .    .    .    .
    5   10   15   20   25   30 - columns
```

Card 9

```
  60.   0.   0.
   5   10   15 - columns
```

Card 10

```
 2
```

Card 11b

```
  4.5  19.  32.102.6  .2  .44  14.  4000.  .71 .55  .6 599.  3.85
   5   10   15   20   25   30   35    45   50   55   60   65   70
```

Card 12

```
   1-1.61 200.  .59 .892  .1   0.    .0004
   5   10   15   20   25   30   35      45 - columns
```

Card 13

0 in column 5

Card 14

0 in column 1

# APPENDIX B

# SAMPLE OUTPUT

SUSTAINED SPEED ESTIMATING RUN 3/3/75 378' CUTTER DATA

*****INPUT DATA*****

APPARENT, AIRCRAFT AND CARGO INPUTS

| ITEM | CARGO WEIGHT | CARGO VCG | GROUP 7 WEIGHT | GROUP 7 VCG | AMMO WEIGHT | AMMO VCG | AIRCRAFT WEIGHT | AIRCRAFT VCG | ELECT LOAD | AREA IN DECKHSE | AREA IN HULL | GROUP 7 COST |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GROUP 700 | 0.0 | 0.0 | 29.7 | 1.450 | 0.0 | 0.0 | 0.0 | 0.0 | 46.640 | 1409. | 2256. | 196000. |
| GROUP 701 | 0.0 | 0.0 | 2.3 | 0.729 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0. | 0. | 0. |
| GROUP 702 | 0.0 | 0.0 | 4.5 | 0.808 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0. | 0. | 0. |
| GROUP 750 | 0.0 | 0.0 | 2.1 | 0.925 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0. | 0. | 0. |
| GROUP 751 | 0.0 | 0.0 | 0.4 | 1.260 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0. | 0. | 0. |
| AIRCRAFT | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.4 | 1.440 | 0.0 | 0. | 0. | 0. |
| AMMUNITION | 0.0 | 0.0 | 0.0 | 0.0 | 37.5 | 0.590 | 0.0 | 0.0 | 0.0 | 0. | 0. | 0. |
| OPTAKES | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0. | 460. | 0. |

ELECTRONICS INPUT

| ITEM | GROUP 4 WEIGHT | GROUP 4 VCG | ELECT LOAD | AREA IN DECKHSE | AREA IN HULL | GROUP 4 COST |
|---|---|---|---|---|---|---|
| GROUP 400 | 10.6 | 0.835 | 117.800 | 1307. | 468.222 | 8000. |
| GROUP 401 | 21.0 | 1.050 | 0.0 | 0. | 0. | 0. |
| GROUP 402 | 10.2 | 1.420 | 0.0 | 0. | 0. | 0. |
| GROUP 403 | 9.2 | 0.967 | 0.0 | 0. | 0. | 0. |
| GROUP 404 | 23.8 | 1.406 | 0.0 | 0. | 0. | 0. |
| GROUP 450 | 5.4 | 1.100 | 0.0 | 0. | 0. | 0. |

MANNING INPUT

NO. OF OFFICERS = 16. NO. OF CPOS = 26. NO. OF ENLISTED MEN = 144.

COST INDICES INPUT

LABOR RATE = 4.75 DOLLARS/HR
GROUP 1 INDEX = 1.40
GROUP 2 INDEX = 1.60
GROUP 3 INDEX = 1.19
GROUP 5 INDEX = 1.55
GROUP 6 INDEX = 1.39

INDICES INCLUDE EFFECTS OF INFLATION AND SPECIAL MATERIAL COSTS

```
MILITARY MISSION CONSUMABLES INPUT

 NO. ENDURANCE DAYS =   90.  WEIGHT AIRCRAFT FUEL =    19.6  VCG AIRCRAFT FUEL =    0.350

VEHICLE PERFORMANCE INPUT
 MAX SUSTAINED SPEED CONDUCTED
MAX SUSTAINED SHP =    36000.
MIN DECKHEIGHT FOR MACHINERY = 22.00 FT
MIN LENGTH OF MACHINERY BOX =  53.00 FT
GROUP 2 WEIGHT =     383.6 TONS
SFC MAX POWER = 0.583 LBS/SHP-HR
SFC HALF POWER = 0.466 LBS/SHP-HR
ENDURANCE SPEED =     14.00 KTS
ENDURANCE RANGE =    10500. MILES
PROP AUX ELECT LOAD =    71.000 KW
PROP COEF ENDURANCE = 0.550
PROP COEF MAXIMUM = 0.600
GROUP 2 COST =  5952426. DOLLARS
WEIGHT OF LUB OIL =      16.0 TONS

 OPTIONS

HTYPE =  2
FREE SURFACE CORRECTION =  0.0  FT
GM MULTIPLIER = 0.100
DESIGN AND BUILDERS MARGIN = 0.0
DELTA CP =  0.00040
LENGTH = 350.0 FT
CP = 0.582
CX = 0.820


                              *****OUTPUT*****

 LENGTH  BEAM   DRAFT  DO    D10   D20   DAVG  LNTH RD  CP    CX   DISPLACEMENT  SHPMAX    VSUS   SHPEND

 350.0   43.32  14.60 38.33 27.83 28.18 29.64      0.0 0.582 0.820    3061.5      36000.   26.44    2647.

AVERAGE SPEED IN SEAWAY IS 23.50 KNOTS

ELECTRIC PLANT CAPACITY/GEN =    1500. KW
```

| | WEIGHTS | VCG | WT/WFULLD | WT/WLSHIP | COST |
|---|---|---|---|---|---|
| WTG1 | 962.8 | 19.425 | 0.314 | 0.435 | 2218029. |
| WTG2 | 383.6 | 11.523 | 0.125 | 0.173 | 5952426. |
| WTG3 | 168.8 | 21.755 | 0.054 | 0.076 | 2436464. |
| WTG4 | 80.2 | 32.520 | 0.026 | 0.036 | 2903021. |
| WTG5 | 262.3 | 19.762 | 0.086 | 0.118 | 3192838. |
| WTG6 | 322.3 | 25.883 | 0.105 | 0.146 | 4377166. |
| WTG7 | 39.0 | 36.296 | 0.013 | 0.018 | 354553. |
| WLSHIP | 2215.0 | 19.981 | 0.724 | 1.000 | 29377856. = TOTAL COST |
| FUEL | 653.2 | 8.350 | 0.213 | | |
| LUB OIL | 16.0 | 3.618 | 0.005 | | |
| CREW | 13.7 | 26.998 | 0.004 | | |
| FPB EFF | 7.8 | 26.998 | 0.003 | | |
| PER STR | 95.1 | 14.357 | 0.031 | | |
| CARGO | 0.0 | 0.0 | 0.0 | | |
| AMMO | 37.5 | 16.422 | 0.012 | | |
| AIR CFT | 3.4 | 40.080 | 0.001 | | |
| A/C FUEL | 19.6 | 9.742 | 0.006 | | |
| WFULLD | 3061.4 | 17.201 | | | |

A MARGIN OF KG OF 0.0 FT EXISTS ABOVE THE FULL LOAD KG VALUE GIVEN

NOTE D&B MARGIN INCLUDED IN WLSHIP AND COST ESTIMATES BUT NOT IN INDIVIDUAL WEIGHT GROUPS
OVERHEAD AND PROFIT ARE INCLUDED IN INDIVIDUAL WEIGHT GROUP COSTS
TOTAL COST INCLUDES A DESIGN COST OF 3305516. DOLLARS
A CONST SERVICES COST OF 939013. DOLLARS
AND A MISC. ITEM COST OF 3699262. DOLLARS
MISC.ITEM COST INCLUDES ORI OUTFIT, SPARES, RETROFIT COSTS, AND ADMINISTRATIVE COSTS(RIO)

VOLUME OF HULL = 273734. CU FT
VOLUME OF DECKHOUSE = 98705. CU FT

| | VOLUME(CU FT) | VOL/ENCVOL |
|---|---|---|
| MACHINERY ROOM | 57390. | 0.156 |
| TANKAGE | 36987. | 0.100 |
| ARRANGEMENTS | 274062. | 0.744 |

TOTAL ARRANGEMENTS AREA = 29654.
HULL ARRANGEMENTS AREA = 18522.
DECKHOUSE ARRANGEMENTS AREA = 11142.

| | AREA (SQ FT) | AREA/TOT AREA |
|---|---|---|
| OFFICE SPACE | 510. | 0.017 |
| MESSING FACILITIES | 2713. | 0.091 |
| CREW SPECIAL | 787. | 0.027 |
| OFFICER S.R. | 1168. | 0.039 |
| OFFICER SANITARY | 192. | 0.006 |
| CPO S.R. | 1040. | 0.035 |
| CPO SANITARY | 208. | 0.007 |
| CREW BERTHING | 3168. | 0.107 |
| CREW SANITARY | 720. | 0.024 |
| C.C. S.R.,CABIN & PANTRY | 753. | 0.025 |
| COMMISSARY STORES | 652. | 0.022 |
| OTHER STORES | 3231. | 0.109 |
| WORKSHOPS | 1254. | 0.042 |
| REPAIR LOCKERS | 100. | 0.003 |
| CHAIN LOCKER | 40. | 0.001 |
| UPTAKES | 0. | 0.0 |
| STEERING GEAR & WINDLASS | 779. | 0.026 |
| A/C & FAN SPACES | 396. | 0.013 |
| I.C. SPACES | 312. | 0.011 |
| AUX MACHINERY SPACES | 2180. | 0.073 |
| PILOT HOUSE,CHARTROOM & CIC | 1111. | 0.037 |
| PASSAGES | 2450. | 0.083 |
| INPUT AREA | 5900. | 0.199 |
| EXCESS AREA | -1. | -0.000 |

CREW SPECIAL INCLUDES SICKBAY,BARBERSHOP,MOVIE LOCKER, LAUNDRY,AND SHIPS STORE

MAN VOL/MAN = 491.2 CUFT/MAN
GR2WT/HP = 0.0107 TONS/HP
MACH ROOM VOL/HP = 1.5942 CUFT/HP
GR1WT/ENGVOL = 0.00261 TONS/CUFT
BYOLLD/ENGVOL = 0.00831 TONS/CUFT
BLSHIP/ENGVOL = 0.00601 TONS/CUFT
GR4COST/TOTCOST = 0.099
GR7COST/TOTCOST = 0.012
VCG/DAVG = 0.580

210 SHIP TEST RUN

*****INPUT DATA*****

ARMAMENT, AIRCRAFT AND CARGO INPUTS

| ITEM | CARGO WEIGHT | CARGO VCG | GROUP 7 WEIGHT | GROUP 7 VCG | AMMO WEIGHT | AMMO VCG | AIRCRAFT WEIGHT | AIRCRAFT VCG | ELECT LOAD | AREA IN DECKHSE | AREA IN HULL | GROUP 7 COST |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GROUP 700 | 0.0 | 0.0 | 4.7 | 1.640 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0. | 385. | 76000. |
| GROUP 701 | 0.0 | 0.0 | 0.6 | 1.010 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0. | 0. | 0. |
| GROUP 702 | 0.0 | 0.0 | 2.8 | 0.600 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0. | 0. | 0. |
| GROUP 750 | 0.0 | 0.0 | 0.4 | 0.310 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0. | 0. | 0. |
| AMMUNITION | 0.0 | 0.0 | 0.0 | 0.0 | 2.6 | 0.410 | 0.0 | 0.0 | 0.0 | 0. | 0. | 0. |

ELECTRONICS INPUT

| ITEM | GROUP 4 WEIGHT | GROUP 4 VCG | ELECT LOAD | AREA IN DECKHSE | AREA IN HULL | GROUP 4 COST |
|---|---|---|---|---|---|---|
| GROUP 400 | 0.7 | 1.850 | 21.990 | 319. | 0. | 190000. |
| GROUP 401 | 2.4 | 1.300 | 0.0 | 0. | 0. | 0. |
| GROUP 402 | 0.2 | 1.560 | 0.0 | 0. | 0. | 0. |
| GROUP 403 | 10.4 | 0.920 | 0.0 | 0. | 0. | 0. |
| GROUP 404 | 9.1 | 2.690 | 0.0 | 0. | 0. | 0. |
| GROUP 450 | 3.3 | 1.760 | 0.0 | 0. | 0. | 0. |

MANNING INPUT

NO. OF OFFICERS = 9. NO. OF CPOS = 8. NO. OF ENLISTED MEN = 57.

COST INDICES INPUT

LABOR RATE = 4.75 DOLLARS/HR
GROUP 1 INDEX = 1.40
GROUP 2 INDEX = 1.60
GROUP 3 INDEX = 1.19
GROUP 5 INDEX = 1.55
GROUP 6 INDEX = 1.39

INDICES INCLUDE EFFECTS OF INFLATION AND SPECIAL MATERIAL COSTS

```
MILITARY MISSION CONSUMABLES INPUT

 NO. ENDURANCE DAYS =   60.  WEIGHT AIRCRAFT FUEL =     0.0  VCG AIRCRAFT FUEL =    0.0

VEHICLE PERFORMANCE INPUT

 PAX SUSTAINED SHP COMPUTED
SUSTAINED SPEED =    17.29 KTS
ENDURANCE SPEED =    14.00 KTS
ENDURANCE RANGE =    4000. MILES
PROP COEF ENDURANCE = 0.550
PROP COEF MAXIMUM = 0.600

 OPTIONS

MTYPE =  1
FREE SURFACE CORRECTION = -1.61 FT
GM MULTIPLIER = 0.100
DESIGN AND BUILDERS MARGIN = 0.0
DELTA CF =  C.00040
LENGTH = 200.0 FT
CF = 0.590
CX = C.892


                              *****OUTPUT*****

 LENGTH  BEAM   DRAFT  DO    D10   D20   DAVG  LWTH BD  CP    CX  DISPLACEMENT  SHPMAX   VSUS   SHPEND

 200.0   33.96   9.12 20.43 18.43 18.63 24.34    130.5 0.590 0.892    943.9      4412.   17.29.   1554.

AVERAGE SPEED IN SEAWAY IS 14.55 KNOTS


ELECTRIC PLANT CAPACITY/GEN =     500. KW
```

| | WEIGHTS | VCG | WT/WFULLD | WT/WLSHIP | COST | |
|---|---|---|---|---|---|---|
| WTG1 | 334.5 | 13.355 | 0.354 | 0.444 | 943392. | |
| WTG2 | 98.9 | 9.014 | 0.105 | 0.131 | 1050790. | |
| WTG3 | 75.4 | 21.424 | 0.080 | 0.100 | 1051032. | |
| WTG4 | 26.1 | 31.476 | 0.028 | 0.035 | 343885. | |
| WTG5 | 104.2 | 19.118 | 0.110 | 0.138 | 1482397. | |
| WTG6 | 105.8 | 24.928 | 0.112 | 0.140 | 1379934. | |
| WTG7 | 8.5 | 21.935 | 0.009 | 0.011 | 127777. | |
| WLSHIP | 753.4 | 16.739 | 0.797 | 1.000 | 8521473. | = TOTAL COST |
| FUEL | 141.2 | 8.078 | 0.149 | | | |
| LUB OIL | 9.4 | 2.396 | 0.010 | | | |
| CREW | 5.5 | 17.874 | 0.006 | | | |
| PER EFF | 3.2 | 17.874 | 0.003 | | | |
| RES STR | 30.4 | 11.439 | 0.032 | | | |
| CARGO | 0.0 | 0.0 | 0.0 | | | |
| AMMO | 2.6 | 7.555 | 0.003 | | | |
| AIR CFT | 0.0 | 0.0 | 0.0 | | | |
| A/C FUEL | 0.0 | 0.0 | 0.0 | | | |
| WFULLD | 945.6 | 15.118 | | | | |

A MARGIN OF KG OF 0.0 FT EXISTS ABOVE THE FULL LOAD KG VALUE GIVEN

NOTE D&B MARGIN INCLUDED IN WLSHIP AND COST ESTIMATES BUT NOT IN INDIVIDUAL WEIGHT GROUPS
OVERHEAD AND PROFIT ARE INCLUDED IN INDIVIDUAL WEIGHT GROUP COSTS
TOTAL COST INCLUDES A DESIGN COST OF 797657. DOLLARS
A CONST SERVICES COST OF 382764. DOLLARS
AND A MISC. ITEM COST OF 961851. DOLLARS
MISC.ITEM COST INCLUDES ORD OUTFIT, SPARES, RETROFIT COSTS, AND ADMINISTRATIVE COSTS(RIC)

VOLUME OF HULL = 115869. CU FT
VOLUME OF DECKHOUSE = 17840. CU FT

| | VOLUME(CU FT) | VOL/ENCVOL |
|---|---|---|
| MACHINERY ROOM | 18167. | 0.136 |
| TANKAGE | 16651. | 0.125 |
| ARRANGEMENTS | 98891. | 0.740 |

TOTAL ARRANGEMENTS AREA = 10661.
HULL ARRANGEMENTS AREA = 8562.
DECKHOUSE ARRANGEMENTS AREA = 2099.

| | AREA(SQ FT) | AREA/TOT AREA |
|---|---|---|
| OFFICE SPACE | 192. | 0.018 |
| MESSING FACILITIES | 1381. | 0.129 |
| CREW SPECIAL | 313. | 0.029 |
| OFFICERS S.R. | 657. | 0.062 |
| OFFICER SANITARY | 108. | 0.010 |
| CIC S.R. | 320. | 0.030 |
| CPO SANITARY | 64. | 0.006 |
| CREW BERTHING | 1254. | 0.118 |
| CREW SANITARY | 285. | 0.027 |
| C.O. S.R.,CABIN & PANTRY | 398. | 0.037 |
| COMMISSARY STORES | 393. | 0.037 |
| OTHER STORES | 1180. | 0.111 |
| WORKSHOPS | 358. | 0.034 |
| REPAIR LOCKERS | 100. | 0.009 |
| CHAIN LOCKER | 40. | 0.004 |
| UPTAKES | 65. | 0.006 |
| STEERING GEAR & WINDLASS | 380. | 0.036 |
| A/C & FAN SPACES | 144. | 0.014 |
| I.C. SPACES | 180. | 0.017 |
| AUX MACHINERY SPACES | 796. | 0.075 |
| PILOT HOUSE,CHARTROOM & CIC | 469. | 0.044 |
| PASSAGES | 881. | 0.083 |
| INPUT AREA | 704. | 0.066 |
| EXCESS AREA | -0. | -0.000 |

CREW SPECIAL INCLUDES SICKBAY,BARBERSHOP,MOVIE LOCKER, LAUNDRY,AND SHIPS STORE

BAR VOL/BAR = 549.0 CUFT/MAN
GR2WT/EP = 0.0224 TONS/HP
EACH ECON VOL/HP = 4.1175 CUFT/HP
GR1WT/ENGVOL = 0.00250 TONS/CUFT
WFULLD/ENGVOL = 0.00707 TONS/CUFT
WLSHIP/ENGVOL = 0.00563 TONS/CUFT
GR4COST/TOTCOST = 0.040
GR7COST/TOTCOST = 0.015
VCG/DAVG = 0.621

# APPENDIX C

## LISTING OF THE PROGRAM

```
      REAL LEN,KGTRY,NOFF,NCPO,NENL                                          MAIN0001
      REAL LRD                                                               MAIN0002
      REAL MCST                                                              MAIN0003
      COMMON/AA/ENDDAY,NOFF,NCPO,NENL                                        MAIN0004
      COMMON/BB/CN,DHV,ENGVOL,DAVG,AREACH,AREAHL,LEN                         MAIN0005
      COMMON/CC/SHPM,SHPE,VSUS,VEND,RGEND,DELCF,SFCMHP,SFCHHP,MTYPE,JOPT     MAIN0006
     1,PCM,PCE                                                               MAIN0007
      COMMON/DD/ELKW,AVGKW,ELOAD,BLOAD,PALOAD                                MAIN0008
      COMMON/EE/GR4WT(20),GR4CG(20),GR7WT(20),GR7CG(20),AMOWT(20),           MAIN0009
     1AMOCG(20),ACWT(20),ACCG(20),          CARGOW(20),CARGOC(20)           MAIN0010
      COMMON/FF/TITLE(5,40),HEAD(20),NOARM,NOELT                             MAIN0011
      COMMON/GG/FRSC,CP,CX,GMMUL,KGTRY,DPTRY,B,H,CWP                         MAIN0012
      COMMON/HH/CGFUEL,CGLO,CGCREW,CGPE,CGPS,CCARGO,CGAMMO,CGAC,CACFUL       MAIN0013
      COMMON/JJ/DHM,XLM,LRD                                                  MAIN0014
      COMMON/KK/ELLD(20),DHAR(20),HLAR(20),ELD(20),DHA(20),HLA(20)           MAIN0015
     1,GR7CST(20),GR4CST(20)                                                 MAIN0016
      COMMON/LL/WTFUEL,WTLO,WTCREW,WTPE,WTPS,WCARGO,WTAMMO,WTAC,WACFUL       MAIN0017
      COMMON/MM/CSTG1,CSTG2,CSTG3,CSTG4,CSTG5,CSTG6,CSTG7,DCST,CCST,MCST     MAIN0018
      COMMON/NN/ DOLHR,G1IND,G2IND,G3IND,G5IND,G6IND,TOTCST                  MAIN0019
      COMMON /TT/CR1(1152),CR2(972),CR3(216)                                 MAIN0020
      COMMON/WW/WTG1,WTG2,WTG3,WTG4,WTG5,WTG6,WTG7,WLSHIP,WFULLD,DBMAR       MAIN0021
      READ(8,120) CR1                                                        MAIN0022
  120 FORMAT(16F5.0)                                                         MAIN0023
      READ(8,121) CR2                                                        MAIN0024
  121 FORMAT(9F5.0)                                                          MAIN0025
      READ(8,122)CR3                                                         MAIN0026
  122 FORMAT(6F5.0)                                                          MAIN0027
    2 READ(8,124) INDEX                                                      MAIN0028
  124 FORMAT(I1)                                                             MAIN0029
      IF(INDEX.EQ.0) STOP                                                    MAIN0030
      READ(8,123)(HEAD(I),I=1,20)                                            MAIN0031
  123 FORMAT(20A4)                                                           MAIN0032
C     ARMAMENT, AIRCRAFT AND CARGO INPUT                                     MAIN0033
      READ(8,100) NOARM                                                      MAIN0034
  100 FORMAT(I2)                                                             MAIN0035
      READ(8,101)((TITLE(J,I),J=1,5),CARGOW(I),CARGOC(I),GR7WT(I),GR7CG      MAIN0036
```

```
     1(I),AMOWT(I),AMOCG(I),ACWT(I),ACCG(I),ELLO(I),DHAR(I),HLAR(I),          MAINC037
     2GR7CST(I),I=1,NOARM)                                                    MAINC038
  101 FORMAT(5A4,12F5.0)                                                      MAINC039
      WCARGO=0.                                                               MAINC040
      WTG7=0.                                                                 MAIN0041
      WTAMMO=0.                                                               MAIN0042
      WTAC=0.                                                                 MAIN0043
      ELOAD=0.                                                                MAINC044
      BLOAD=0.                                                                MAINC045
      AREADH=0.                                                               MAIN0046
      AREAHL=0.                                                               MAINC047
      CSTG7=0.                                                                MAIN0048
      DO 10 I=1,NOARM                                                         MAIN0049
      WCARGO=WCARGO+CARGOW(I)                                                 MAIN0050
      WTG7=WTG7+GR7WT(I)                                                      MAIN0051
      WTAMMO=WTAMMO+AMOWT(I)                                                  MAIN0052
      WTAC=WTAC+ACWT(I)                                                       MAIN0053
      BLOAD=BLOAD+ELLD(I)                                                     MAINC054
      GR7CST(I)=GR7CST(I)*1000.                                               MAIN0055
      CSTG7=CSTG7+GR7CST(I)                                                   MAIN0056
      AREADH=AREADH+DHAR(I)                                                   MAINC057
   10 AREAHL=AREAHL+HLAR(I)                                                   MAIN0058
C     ELECTRONICS INPUT                                                       MAIN0059
      READ(8,102) NOELT                                                       MAIN0060
  102 FORMAT(I2)                                                              MAIN0061
      READ(8,103)((TITLE(J,I+20),J=1,5),GR4WT(I),GR4CG(I),ELD(I),DHA(I),      MAIN0062
     1HLA(I),GR4CST(I),I=1,NOELT)                                             MAIN0063
  103 FORMAT(5A4,6F5.0)                                                       MAINC064
      WTG4=0.                                                                 MAIN0065
      CSTG4=0.                                                                MAIN0066
      DO 11 I=1,NOELT                                                         MAIN0067
      WTG4=WTG4+GR4WT(I)                                                      MAIN0068
      ELOAD=ELOAD+ELD(I)                                                      MAIN0069
      GR4CST(I)=GR4CST(I)*1000.                                               MAIN0070
      CSTG4=CSTG4+GR4CST(I)                                                   MAIN0071
      AREADH=AREADH+DHA(I)                                                    MAIN0072
```

```
   11 AREAHL=AREAHL+FLA(I)                                                  MAIN0073
      G4CST=CSTG4                                                           MAIN0074
      G7CST=CSTG7                                                           MAIN0075
C     MANNING INPUT                                                         MAIN0076
      READ(8,104) NOOFF,NOCPC,NOCREW                                        MAIN0077
  104 FORMAT(3I5)                                                           MAIN0078
      NOFF=FLOAT(NOOFF)                                                     MAIN0079
      NCPO=FLOAT(NOCPC)                                                     MAIN0080
      NENL=FLOAT(NOCREW)                                                    MAIN0081
C     COST INDICES INPUT                                                    MAIN0082
      READ(8,110) DOLHR,G1IND,G2IND,G3IND,G5IND,G6IND                       MAIN0083
  110 FORMAT(6F5.0)                                                         MAIN0084
C     MILITARY MISSION CONSUMABLES INPUT                                    MAIN0085
      READ(8,105) ENDDAY,WACFUL,CACFUL                                      MAIN0086
  105 FORMAT(3F5.0)                                                         MAIN0087
      HPMS=0.                                                               MAIN0088
C     VEHICLE PERFORMANCE INPUT                                             MAIN0089
      READ(8,106) JOPT                                                      MAIN0090
  106 FORMAT(I2)                                                            MAIN0091
C     (1 COMPUTE MAX HP, 2 COMPUTE SPEED)                                   MAIN0092
      IF(JOPT.EQ.2) GOTO 1                                                  MAIN0093
      READ(8,107) VSUS,VEND,RGEND,PCE,PCM                                   MAIN0094
  107 FORMAT(2F5.0,F10.0,2F5.0)                                             MAIN0095
      GOTO 9                                                                MAIN0096
    1 READ(8,108) HPMS,DHM,XLM,WTG2,SFCMHP,SFCHHP,VEND,RGEND,PALOAD,PCE,    MAIN0097
     1PCM,CSTG2,WTLO                                                        MAIN0098
  108 FORMAT(7F5.0,F10.0,5F5.0)                                             MAIN0099
      HPMS=HPMS*1000.                                                       MAIN0100
      CSTG2=CSTG2*1000.                                                     MAIN0101
      GR2CST=CSTG2                                                          MAIN0102
C     OPTIONS                                                               MAIN0103
    9 READ(8,109) MTYPE,FRSC,LEN,CP,CX,GMMUL,DBMAR,DELCF                   MAIN0104
C     MTYPE = 1 DIESEL,MTYPE = 2 CODOG                                      MAIN0105
  109 FORMAT(I5,6F5.0,F10.0)                                                MAIN0106
      IF(MTYPE.EQ.0) GOTO 2                                                 MAIN0107
      DBMAR=1.+DBMAR                                                        MAIN0108
```

```
CSTG2=GR2CST                                                          MAIN0109
CSTG4=G4CST                                                           MAIN0110
CSTG7=G7CST                                                           MAIN0111
KGTRY=LEN/(.0465*LEN+4.825)                                           MAIN0112
KGTRY=KGTRY-2.                                                        MAIN0113
DPTRY=(.006562-.001188*LEN/100.)*LEN**3/35.                           MAIN0114
IF(INDEX.EQ.2) DPTRY=.0025*LEN**3/35.                                 MAIN0115
CN=DPTRY*160.                                                         MAIN0116
CALL XECUTE(HPMS)                                                     MAIN0117
GOTO 9                                                                MAIN0118
END                                                                   MAIN0119
```

```
      SUBROUTINE XECUTE(HPMS)                                                    XEC 0001
      REAL LEN,KGTRY                                                             XEC 0002
      COMMON/BB/CN,DHV,ENCVOL,DAVG,AREADH,AREAHL,LEN                             XEC 0003
      COMMON/CC/SHPM,SHPE,VSUS,VE,RE,DELCF,SFCM,SFCH,MTYPE,JOPT,PCM,PCE          XEC 0004
      COMMON/GG/FRSC,CP,CX,GMMUL,KGTRY,OPTRY,B,H,CWP                             XEC 0005
      COMMON/WW/WTG1,WTG2,WTG3,WTG4,WTG5,WTG6,WTG7,WLSHIP,WFULLD,DBMAR           XEC 0006
      EXCKG=0.                                                                   XEC 0007
      JNDEX=1                                                                    XEC 0008
      LNDEX=1                                                                    XEC 0009
    7 CALL UWDIM(R)                                                              XEC 0010
      IF(LEN.LT.0.) GOTO 999                                                     XEC 0011
      IF(JOPT.EQ.2) GOTO 1                                                       XEC 0012
      CALL HPCALC(VSUS,SHP,PCM)                                                  XEC 0013
      IF(LEN.LT.0.) GOTO 998                                                     XEC 0014
      GOTO 2                                                                     XEC 0015
    1 VMAX=(HPMS*200./LEN)**.33333                                               XEC 0016
    4 CALL HPCALC(VMAX,SHP,PCM)                                                  XEC 0017
      IF(LEN.LT.0.) GOTO 998                                                     XEC 0018
      SHP1=SHP                                                                   XEC 0019
      VMAX1=.95*VMAX                                                             XEC 0020
      CALL HPCALC(VMAX1,SHP,PCM)                                                 XEC 0021
      IF(LEN.LT.0.) GOTO 998                                                     XEC 0022
      SHP2=SHP                                                                   XEC 0023
      DELHP=(SHP1-SHP2)/(VMAX-VMAX1)                                             XEC 0024
      VMAX1=VMAX-(SHP1-.8*HPMS)/DELHP                                            XEC 0025
      IF(ABS(VMAX1-VMAX).LE.VMAX1*.005) GOTO 3                                   XEC 0026
      VMAX=VMAX1                                                                 XEC 0027
      GOTO 4                                                                     XEC 0028
    3 VSUS=VMAX1                                                                 XEC 0029
      SHPM=HPMS                                                                  XEC 0030
      GOTO 5                                                                     XEC 0031
    2 SHPM=SHP/.8                                                                XEC 0032
      IF(MTYPE.EQ.1.AND.SHPM.GT.14000.) GO TO 997                                XEC 0033
    5 CALL HPCALC(VE,SHP,PCE)                                                    XEC 0034
      IF(LEN.LT.0.) GOTO 998                                                     XEC 0035
      SHPE=SHP                                                                   XEC 0036
```

```
      CALL EPLANT                                                       XEC 0037
      CALL MACHLQ                                                       XEC 0038
      IF(JOPT.EQ.2) GOTO 6                                              XEC 0039
      CALL MBSIZE (B)                                                   XEC 0040
    6 CALL VOLUME                                                       XEC 0041
      IF(LEN.LT.0.) GOTO 996                                            XEC 0042
      CALL WEIGHT                                                       XEC 0043
      IF(ABS(WFULLD-DPTRY).LT.2.) GO TO 8                               XEC 0044
      IF(LNDEX.GE.2) GOTO 9                                             XEC 0045
      WT1=WFULLC                                                        XEC 0046
      DP1=DPTRY                                                         XEC 0047
      DPTRY=WFULLD                                                      XEC 0048
      GOTO 10                                                           XEC 0049
    9 FACTOR=(DPTRY-WFULLD-DP1+WT1)/(DPTRY-DP1)                         XEC 0050
      DP1=DPTRY                                                         XEC 0051
      WT1=WFULLD                                                        XEC 0052
      DPTRY=DPTRY-(DPTRY-WFULLD)/FACTOR                                 XEC 0053
   10 IF(LNDEX.GT.20) GOTO 995                                          XEC 0054
      LNDEX=LNDEX+1                                                     XEC 0055
      GOTO 7                                                            XEC 0056
    8 CONTINUE                                                          XEC 0057
      LNDEX=1                                                           XEC 0058
      CALL VCG(CFULLD)                                                  XEC 0059
      IF(ABS(CFULLD-KGTRY).LT..1) GOTO 11                               XEC 0060
      IF(JNDEX.GT.21) GOTO 994                                          XEC 0061
      IF(CFULLD.LT.KGTRY) GOTO 12                                       XEC 0062
   13 KGTRY=(CFULLD+KGTRY)/2.                                           XEC 0063
      JNDEX=JNDEX+1                                                     XEC 0064
      GOTO 7                                                            XEC 0065
   12 IF(R.LT..001) GOTO 13                                             XEC 0066
      EXCKG=KGTRY-CFULLD                                                XEC 0067
   11 CONTINUE                                                          XEC 0068
      CALL COST(LEN)                                                    XEC 0069
      CALL SEASPD(AVSP)                                                 XEC 0070
      CALL OUTPUT(AVSP,EXCKG,2)                                         XEC 0071
      RETURN                                                            XEC 0072
```

```
 994 CALL OUTPUT(0.,0.,1)                                                XEC 0073
     WRITE(5,106)                                                        XEC 0074
 106 FORMAT(///' NO BALANCE BETWEEN ASSUMED AND CALC KG WITHIN 0.1 FEET  XEC 0075
    1 COULD BE MADE IN 20 ITERATIONS'///)                                XEC 0076
     GOTO 1000                                                           XEC 0077
 995 CALL OUTPUT(0.,0.,1)                                                XEC 0078
     WRITE(5,105)                                                        XEC 0079
 105 FORMAT(///' NO BALANCE BETWEEN WEIGHT AND DISPLACEMENT WITHIN 2     XEC 0080
    1TONS COULD BE MADE IN 20 ITERATIONS'///)                            XEC 0081
     GOTO 1000                                                           XEC 0082
 996 CALL OUTPUT(0.,0.,1)                                                XEC 0083
     WRITE(5,104)                                                        XEC 0084
 104 FORMAT(///' TOO LARGE A VOLUME REQUIRED FOR SOLUTION USING INPUT    XEC 0085
    1LENGTH, TRY A LONGER SHIP'///)                                      XEC 0086
     GOTO 1000                                                           XEC 0087
 997 CALL OUTPUT(0.,0.,1)                                                XEC 0088
     WRITE(5,103)                                                        XEC 0089
 103 FORMAT(///' REQUIRED HP EXCEEDS STORED DATA. INPUT MACHINERY DATA   XEC 0090
    1 USING JOPT=2'///)                                                  XEC 0091
     GOTO 1000                                                           XEC 0092
 998 CALL OUTPUT(0.,0.,1)                                                XEC 0093
     WRITE(5,101)                                                        XEC 0094
 101 FORMAT(///' LIMITS OF STORED RESISTANCE DATA EXCEEDED'///)          XEC 0095
     GOTO 1000                                                           XEC 0096
 999 CALL OUTPUT(0.,0.,1)                                                XEC 0097
     WRITE(5,100)                                                        XEC 0098
 100 FORMAT(///' VCG IS ABOVE LIMITS OF STORED DATA'///)                 XEC 0099
1000 WRITE(5,102)                                                        XEC 0100
 102 FORMAT(' PROGRAM PROCEEDING TO NEXT INPUT CASE'///)                 XEC 0101
     RETURN                                                              XEC 0102
     END                                                                 XEC 0103
```

```
      SUBROUTINE UWDIM(R)                                                UWDM0001
      REAL LEN                                                           UWDM0002
      DIMENSION A(5),B(5),C(5)                                           UWDM0003
      COMMON/BB/CN,DPV,ENCVOL,DAVG,AREADH,AREAHL,LEN                     UWDM0004
      COMMON/GG/FRSC,CP,CX,C5,C4,DISPL,B1,H,CWP                          UWDM0005
      DPTRY=DISPL/1.014                                                  UWDM0006
      CWP=.8065*CP+.2645                                                 UWDM0007
      CALPH=.12*CWP-.0414                                                UWDM0008
      C1=DPTRY*35./(LEN*CP*CX)                                           UWDM0009
      C2=.833-CP*CX/(3.*CWP)                                             UWDM0010
      C3=LEN*CALPH/(DPTRY*35.)                                           UWDM0011
      C4=C4+FRSC                                                         UWDM0012
C     R=KB+BM-KG-FRSC-GM=C2*H+C3*B**3-C4-C5*B                            UWDM0013
C     H=C1/B                                                             UWDM0014
C     DR/DB=-C1*C2/B**2+3*C3*B**2-C5=0 FOR MINIMUM POINT                 UWDM0015
      BMIN=SQRT((C5+SQRT(C5**2+12.*C1*C2*C3))/(6.*C3))                   UWDM0016
      HMIN=C1/BMIN                                                       UWDM0017
      BTR=BMIN/HMIN                                                      UWDM0018
      IF(BTR.LT.2..OR.BTR.GT.4.) GOTO 1                                  UWDM0019
      R=C2*HMIN+C3*BMIN**3-C4-C5*BMIN                                    UWDM0020
      IF(R.LE.0.0) GOTO 2                                                UWDM0021
      C4=C4-FRSC+R                                                       UWDM0022
      B1=BMIN                                                            UWDM0023
      H=HMIN                                                             UWDM0024
      RETURN                                                             UWDM0025
    1 HMAX=SQRT(C1/2.005)                                                UWDM0026
      BMIN=C1/HMAX                                                       UWDM0027
      R=C2*HMAX+C3*BMIN**3-C4-C5*BMIN                                    UWDM0028
      IF(R.LE.0.0) GOTO 2                                                UWDM0029
      C4=C4-FRSC+R                                                       UWDM0030
      B1=BMIN                                                            UWDM0031
      H=HMAX                                                             UWDM0032
      RETURN                                                             UWDM0033
    2 HMIN=SQRT(C1/3.995)                                                UWDM0034
      BMAX=C1/HMIN                                                       UWDM0035
      R=C2*HMIN+C3*BMAX**3-C4-C5*BMAX                                    UWDM0036
```

```
      IF(R.LT.0.0) GOTO 6                                                UWDM0037
      A(1)=1.0                                                           UWDM0038
      A(2)=-C4/C2                                                        UWDM0039
      A(3)=-C1*C5/C2                                                     UWDM0040
      A(4)=0.0                                                           UWDM0041
      A(5)=C3/C2*C1**3                                                   UWDM0042
      B(1)=1.0                                                           UWDM0043
      C(1)=1.0                                                           UWDM0044
      Z=HMIN                                                             UWDM0045
C     H**4-C4/C2*H**3-C1/C2*C5*H**2-C1**3*C3/C2=0                        UWDM0046
    3 DO 4 I=2,5                                                         UWDM0047
      B(I)=A(I)+Z*B(I-1)                                                 UWDM0048
    4 C(I)=B(I)+Z*C(I-1)                                                 UWDM0049
      ZNEW=Z-B(5)/C(4)                                                   UWDM0050
      IF(ABS(ZNEW-Z).LE.0.01*ZNEW) GOTO 5                                UWDM0051
      Z=ZNEW                                                             UWDM0052
      GO TO 3                                                            UWDM0053
    5 H=ZNEW                                                             UWDM0054
      B1=C1/H                                                            UWDM0055
      C4=C4-FRSC                                                         UWDM0056
      R=0.                                                               UWDM0057
      RETURN                                                             UWDM0058
    6 LEN=-1000.0                                                        UWDM0059
      RETURN                                                             UWDM0060
      END                                                                UWDM0061
```

```
      SUBROUTINE HPCALC(VK,SHPS,PC)                                          HPCL0001
      REAL LEN,KGTRY                                                         HPCL0002
      COMMON/CC/SHPN,SHPE,VSUS,VE,RE,DELCF,SFCN,SFCH,MTYPE,JCPT,PCN,PCE      HPCL0003
      COMMON/BB/CN,DHV,ENCVOL,DAVG,AREACH,AREAHL,LEN                         HPCL0004
      COMMON/GG/FRSC,CP,CX,GMMUL,KGTRY,OPTRY,B,H,CWP                         HPCL0005
      DISPL=OPTRY/1.014                                                      HPCL0006
      VOL=DISPL*35.                                                          HPCL0007
      BDR=B/H                                                                HPCL0008
      RN=VK*LEN*132050.                                                      HPCL0009
      CF=.075/(ALOG10(RN)-2.)**2+DELCF                                       HPCL0010
      SLRAT=VK/(SQRT(LEN))                                                   HPCL0011
      CV=VOL/(LEN)**3                                                        HPCL0012
      IF(BDR.LT.2..OR.BDR.GT.4.) GOTO 1000                                   HPCL0013
      IF(CP.LT..48.OR.CP.GT..7) GOTO 1000                                    HPCL0014
      IF(SLRAT.LT..5.OR.SLRAT.GT.2.) GOTO 1000                               HPCL0015
      IF(CV.LT..001.OR.CV.GT..006) GOTO 1000                                 HPCL0016
      IF(CV.GT..003.AND.SLRAT.GT.1.3) GOTO 1000                              HPCL0017
      CALL CRVAL(BDR,CV,CP,SLRAT,CR)                                         HPCL0018
      CT=CF+CR*.001                                                          HPCL0019
      S=(1.7*LEN*H+VOL/H)*(.0053*BDR*BDR-.02*BDR+3.*CV+.08*CP+.926)          HPCL0020
      A=.00438*1.9905*S                                                      HPCL0021
      EHPBH=A*VK**3*CT                                                       HPCL0022
      EHPAPP=(1.467-.2*SLRAT)*EHPBH                                          HPCL0023
      EHP=.9*EHPAPP                                                          HPCL0024
      IF(SLRAT.LT.1.4.AND.SLRAT.GT..9) EHP=(1.74-.6*SLRAT)*EHPAPP            HPCL0025
      IF(SLRAT.LE..9)EHP=1.2*EHPAPP                                          HPCL0026
      SHPS=EHP/PC                                                            HPCL0027
      RETURN                                                                 HPCL0028
1000  LEN=-1000.                                                             HPCL0029
      RETURN                                                                 HPCL0030
      END                                                                    HPCL0031
```

```
      SUBROUTINE CRVAL(BTR,CV,CP,VL,CR)                                 CRVL0001
      COMMON /TT/CR1(1152),CR2(972),CR3(216)                            CRVL0002
      I1(J,K,L,M)=(K-1)*384+(J-1)*192+(L-1)*16+M                        CRVL0003
      I2(J,K,L,M)=(K-1)*324+(J-3)*108+(L-1)*9+M                         CRVL0004
      I3(J,K,L,M)=(K-1)*72+(L-1)*6+M                                    CRVL0005
      IF(BTR.GE.3.) K1=2                                                CRVL0006
      IF(BTR.LT.3.) K1=1                                                CRVL0007
      K2=K1+1                                                           CRVL0008
      CP1=.68                                                           CRVL0009
    3 IF(CP-CP1+.0001) 1,2,2                                            CRVL0010
    1 CP1=CP1-.02                                                       CRVL0011
      GOTO 3                                                            CRVL0012
    2 L1=IFIX((CP1-.46)*50.1)                                           CRVL0013
      L2=L1+1                                                           CRVL0014
      CV1=.005                                                          CRVL0015
    4 IF(CV-CV1+.00001) 5,6,6                                           CRVL0016
    5 CV1=CV1-.001                                                      CRVL0017
      GO TO 4                                                           CRVL0018
   13 J1=J1-1                                                           CRVL0019
      CV1=CV1-.001                                                      CRVL0020
      GOTO 14                                                           CRVL0021
    6 J1=IFIX(CV1*1001.)                                                CRVL0022
      IF(J1.EQ.5.AND.VL.GT.1.) GOTO 13                                  CRVL0023
      IF(J1.EQ.2.AND.VL.GT.1.3) GOTO 13                                 CRVL0024
   14 J2=J1+1.                                                          CRVL0025
      VL1=1.9                                                           CRVL0026
    7 IF(VL-VL1+.0001) 8,9,9                                            CRVL0027
    8 VL1=VL1-.1                                                        CRVL0028
      GOTO 7                                                            CRVL0029
    9 M1=IFIX((VL1-.4)*10.1)                                            CRVL0030
      M2=M1+1                                                           CRVL0031
      J=J1                                                              CRVL0032
      INDEX=1                                                           CRVL0033
   11 IF(J.GE.3) GOTO10                                                 CRVL0034
      I=I1(J,K1,L1,M1)                                                  CRVL0035
      CRA=CR1(I)                                                        CRVL0036
```

```
      I=I1(J,K1,L1,M2)                                                  CRVL0037
      CRB=CR1(I)                                                        CRVL0038
      I=I1(J,K1,L2,M1)                                                  CRVL0039
      CRC=CR1(I)                                                        CRVL0040
      I=I1(J,K1,L2,M2)                                                  CRVL0041
      CRD=CR1(I)                                                        CRVL0042
      I=I1(J,K2,L1,M1)                                                  CRVL0043
      CRE=CR1(I)                                                        CRVL0044
      I=I1(J,K2,L1,M2)                                                  CRVL0045
      CRF=CR1(I)                                                        CRVL0046
      I=I1(J,K2,L2,M1)                                                  CRVL0047
      CRG=CR1(I)                                                        CRVL0048
      I=I1(J,K2,L2,M2)                                                  CRVL0049
      CRH=CR1(I)                                                        CRVL0050
      GOTO 50                                                           CRVL0051
   10 IF(J.EQ.6) GO TO 12                                               CRVL0052
      I=I2(J,K1,L1,M1)                                                  CRVL0053
      CRA=CR2(I)                                                        CRVL0054
      I=I2(J,K1,L1,M2)                                                  CRVL0055
      CRB=CR2(I)                                                        CRVL0056
      I=I2(J,K1,L2,M1)                                                  CRVL0057
      CRC=CR2(I)                                                        CRVL0058
      I=I2(J,K1,L2,M2)                                                  CRVL0059
      CRD=CR2(I)                                                        CRVL0060
      I=I2(J,K2,L1,M1)                                                  CRVL0061
      CRE=CR2(I)                                                        CRVL0062
      I=I2(J,K2,L1,M2)                                                  CRVL0063
      CRF=CR2(I)                                                        CRVL0064
      I=I2(J,K2,L2,M1)                                                  CRVL0065
      CRG=CR2(I)                                                        CRVL0066
      I=I2(J,K2,L2,M2)                                                  CRVL0067
      CRH=CR2(I)                                                        CRVL0068
      GO TO 50                                                          CRVL0069
   12 I=I3(J,K1,L1,M1)                                                  CRVL0070
      CRA=CR3(I)                                                        CRVL0071
      I=I3(J,K1,L1,M2)                                                  CRVL0072
```

```
      CRB=CR3(I)                                                        CRVL0073
      I=I3(J,K1,L2,M1)                                                  CRVL0074
      CRC=CR3(I)                                                        CRVL0075
      I=I3(J,K1,L2,M2)                                                  CRVL0076
      CRD=CR3(I)                                                        CRVL0077
      I=I3(J,K2,L1,M1)                                                  CRVL0078
      CRE=CR3(I)                                                        CRVL0079
      I=I3(J,K2,L1,M2)                                                  CRVL0080
      CRF=CR3(I)                                                        CRVL0081
      I=I3(J,K2,L2,M1)                                                  CRVL0082
      CRG=CR3(I)                                                        CRVL0083
      I=I3(J,K2,L2,M2)                                                  CRVL0084
      CRH=CR3(I)                                                        CRVL0085
   50 V=(VL-VL1)*10.                                                    CRVL0086
      C=(CP-CP1)*50.                                                    CRVL0087
      BTR1=FLOAT((K1-1))*.75+2.25                                       CRVL0088
      B=(BTR-BTR1)/.75                                                  CRVL0089
      C1=(CRB-CRA)*V+CRA                                                CRVL0090
      C2=(CRD-CRC)*V+CRC                                                CRVL0091
      C3=(CRF-CRE)*V+CRE                                                CRVL0092
      C4=(CRH-CRG)*V+CRG                                                CRVL0093
      C5=(C2-C1)*C+C1                                                   CRVL0094
      C6=(C4-C3)*C+C3                                                   CRVL0095
      C7=(C6-C5)*B+C5                                                   CRVL0096
      IF(INDEX.GE.2) GO TO 51                                           CRVL0097
      A=C7                                                              CRVL0098
      J=J2                                                              CRVL0099
      INDEX=2                                                           CRVL0100
      GO TO 11                                                          CRVL0101
   51 D=C7                                                              CRVL0102
      CR=(D-A)*(CV-CV1)*1000.+A                                         CRVL0103
      RETURN                                                            CRVL0104
      END                                                               CRVL0105
```

```
      SUBROUTINE EPLANT                                                  EPLT0001
      REAL LEN,NOFF,NCPO,NENL,NAC,KW,KW1                                 EPLT0002
      COMMON/AA/ENDDAY,NOFF,NCPO,NENL                                    EPLT0003
      COMMON/BB/CN,DHV,ENCVOL,DAVG,AREADH,AREAHL,LEN                     EPLT0004
      COMMON/CC/SHPM,SHPE,VSUS,VE,RE,DELCF,SFCM,SFCH,MTYPE,JOPT,PCM,PCE  EPLT0005
      COMMON/DD/ELKW,AVGKW,ELOAD,BLOAD,PALOAD                            EPLT0006
      IF(JOPT.EQ.2) GOTO 1                                               EPLT0007
      PALOAD=1.                                                          EPLT0008
      IF(MTYPE.EQ.2) PALOAD=71.                                          EPLT0009
    1 OALOAD=.0002695*CN                                                 EPLT0010
      NAC=NOFF+NCPO+NENL                                                 EPLT0011
      HLOAD=.917*NAC                                                     EPLT0012
      AVLOAD=15.+.376*NAC*CN/100000.                                     EPLT0013
      KW=ELOAD+BLOAD+PALOAD+OALOAD+HLOAD+AVLOAD                          EPLT0014
      AVGKW=KW-BLOAD                                                     EPLT0015
      KW1=1.25*(1.02*KW+ELOAD)                                           EPLT0016
      ELKW=100.                                                          EPLT0017
    2 IF(ELKW.GE.KW1) GOTO 3                                             EPLT0018
      IF(ELKW.LT.240.) GOTO 4                                            EPLT0019
      IF(ELKW.LT.900.) GOTO 5                                            EPLT0020
      ELKW=ELKW+500.                                                     EPLT0021
      GOTO 2                                                             EPLT0022
    4 ELKW=ELKW+50.                                                      EPLT0023
      GOTO 2                                                             EPLT0024
    5 ELKW=ELKW+250.                                                     EPLT0025
      GOTO 2                                                             EPLT0026
    3 RETURN                                                             EPLT0027
      END                                                                EPLT0028
```

```
      SUBROUTINE MACHLQ                                                 MHLQC001
      REAL NOFF,NCPO,NENL,NAC                                           MHLQ0002
      COMMON/AA/ENDDAY,NOFF,NCPO,NENL                                   MHLQ0003
      COMMON/CC/SHPM,SHPE,VSUS,VE,RE,DELCF,SFCM,SFCH,MTYPE,JOPT,PCM,PCF MHLQC004
      COMMON/DD/ELKW,AVGKW,ELOAD,BLOAD,PALOAD                           MHLQ0005
      COMMON/LL/WTFUEL,WTLO,WTCREW,WTPE,WTPS,WCARGO,WTAMMO,WTAC,WACFUL  MHLQ0006
      NAC=NOFF+NCPO+NENL                                                MHLQ0007
      WTPS=.186*NAC                                                     MHLQC008
      IF(JOPT.EQ.2) GOTO 1                                              MHLQ0009
      WTLO=.001*SHPM+5.                                                 MHLQ0010
      IF(MTYPE.EQ.2)WTLO=.0001*SHPM+.001*SHPE+8.5                       MHLQC011
      IF(MTYPE.EQ.2) GOTO 2                                             MHLQ0012
      SFC=.5-.08*SHPE/SHPM                                              MHLQ0013
      SHPH=SHPM/2.                                                      MHLQ0014
      IF(SHPM.GT.7000..AND.SHPE.LT.SHPH) SFC=.5-.16*SHPE/SHPM           MHLQ0015
      GOTO 3                                                            MHLQ0016
    2 IF(SHPE.LT.7000.) GOTO 4                                          MHLQ0017
      SFC=(1.38-.38*SHPE/50000.)*.5                                     MHLQ0018
      IF(SHPM.LE.25000.) SFC=(1.38-.38*SHPE/25000.)*.5                  MHLQ0019
      IF(SHPM.GT.25000..AND. SHPM.LE.35000.)SFC=(1.38-.38*SHPE/35000.)  MHLQ0020
     1*.5                                                               MHLQ0021
      GOTO 3                                                            MHLQ0022
    4 SFC=.42                                                           MHLQ0023
      GOTO 3                                                            MHLQ0024
    1 SFC=SFCM+(1.-SHPE/SHPM)*2.*(SFCH-SFCM)                            MHLQ0025
    3 FRMAIN=SFC*SHPE                                                   MHLQ0026
      FRHOTL=.32*NAC                                                    MHLQ0027
      FRGEN=.65*AVGKW                                                   MHLQ0028
      FR=FRMAIN+FRHOTL+FRGEN                                            MHLQ0029
      WTFUEL=FR*RE/(1788.*VE)                                           MHLQ0030
      RETURN                                                            MHLQ0031
      END                                                               MHLQ0032
```

```
      SUBROUTINE MBSIZE (B)                                                    MBSZ0001
      REAL LRD                                                                 MBSZ0002
      COMMON/CC/SHPM,SHPE,VSOS,VE,RE,DELCE,SECM,SECH,MTYPE,JCPT,PCM,PCE        MBSZ0003
      COMMON/JJ/DHM,XLM,LRD                                                    MBSZ0004
      IF(MTYPE.EQ.2) GOTO 1                                                    MBSZ0005
      XLM=1050./B                                                              MBSZ0006
      IF(SHPM.GT.7000..AND.XLM.LT.56.) XLM=56.                                 MBSZ0007
      IF(SHPM.LE.7000..AND.XLM.LT.28.) XLM=28.                                 MBSZ0008
      GOTO 2                                                                   MBSZ0009
    1 XLM=2300./B                                                              MBSZ0010
      IF(XLM.LT.45.) XLM=45.                                                   MBSZ0011
    2 DHM=11.+.0157*SHPM                                                       MBSZ0012
      IF(DHM.GT.22.) DHM=22.                                                   MBSZ0013
      RETURN                                                                   MBSZ0014
      END                                                                      MBSZ0015
```

```
      SUBROUTINE VOLUME                                                 VOL 0001
      REAL LEN,LMB,LRD,NOFF,NCPO,NENL,KGTRY,NAC,LRD1                    VOL 0002
      COMMON/AA/D,NOFF,NCPO,NENL                                        VOL 0003
      COMMON/BB/CN,DHV,ENCVOL,DAVG,AREACH,AREAHL,LEN                    VOL 0004
      COMMON/CC/SHPM,SHPE,VSUS,VF,RF,DELCF,SFCM,SFCH,MTYPE,JOPT,PCM,PCF VOL 0005
      COMMON/GG/FRSC,CP,CX,GMMUL,KGTRY,OPTRY,B,H,CWP                    VOL 0006
      COMMON/II/DO,D10,D20                                              VOL 0007
      COMMON/JJ/DMB,LMB,LRD                                             VOL 0008
      COMMON/LL/WTFUEL,WTLO,WTCREW,WTPE,WTPS,WCARGO,WTAMMO,WTAC,WACFUL  VOL 0009
      COMMON/PP/VMB,TANKVL,AVAA,DHAA,ODA,XMFDA,CSDA,OSRDA,OHCA,CPODA,   VOL 0010
     1CPOHDA,CBDA,CHDA,CODA,CSTDA,OSDA,WDA,RLCA,CLDA,UTCA,SGCA,ACDA,XICD VOL 0011
     2A,AMDA,PHDA                                                       VOL 0012
      KNDEX=0                                                           VOL 0013
      NAC=NOFF+NCPO+NENL                                                VOL 0014
      DECKHT=0.                                                         VOL 0015
      LRD=0.                                                            VOL 0016
      LRD1=0.                                                           VOL 0017
   13 CALL SHEER(DMB,F0,F10,F20,D0,D10,D20,LEN,H,DECKHT)                VOL 0018
      AREA=LEN/6.*(F0+F20+4.*F10)                                       VOL 0019
      FAVG=AREA/LEN                                                     VOL 0020
      DAVG=FAVG+H                                                       VOL 0021
      F7=-.018828*(DAVG/H)**2+.18098*DAVG/H+.714599                     VOL 0022
      HVAW=LEN*B*CWP*FAVG*F7                                            VOL 0023
      HVBW=LEN*B*H*CP*CX                                                VOL 0024
      THV=HVAW+HVBW                                                     VOL 0025
      AM=B*H*CX+B*F10                                                   VOL 0026
      X=LMB/LEN                                                         VOL 0027
      CPM=-.525*X*X+.055*X+.99675                                       VOL 0028
      CPM=CPM+3.2*X*X*(CP-.6)                                           VOL 0029
      VMB=LMB*AM*CPM                                                    VOL 0030
      AHVOM=THV-VMB                                                     VOL 0031
      Q=(-.9037115+.2139727*D10-1.38263E-2*D10**2+4.008058E-4*D10**3    VOL 0032
     1-5.489481E-6*D10**4+2.892153E-8*D10**5)*CP/.58*CX/.814*(1.11*LMB/ VOL 0033
     2LEN+.667)                                                         VOL 0034
      ATVOM=Q*AHVOM                                                     VOL 0035
      VFUEL=WTFUEL*43.                                                  VOL 0036
```

```
      VLO=WTLO*39.                                                                VOL 0037
      VFW=.186*NAC*36.                                                            VOL 0038
      VACFUL=WACFUL*44.1                                                          VOL 0039
      VREQ=(VFUEL+VLO+VFW+VACFUL)*1.2                                             VOL 0040
      RTAA=0.                                                                     VOL 0041
      IF(VREQ.GT.ATVOM) RTAA=(VREQ-ATVOM)/8.5                                     VOL 0042
      AAVOM=AHVOM-ATVOM                                                           VOL 0043
      TANKVL=ATVOM+RTAA*8.5                                                       VOL 0044
      P=(6.510417E-7*D10**3-7.851484E-5*D10**2+3.438375E-3*D10+.0530399)          VOL 0045
     1*(.191*CP+.8893)*(.191*CX+.8445)*(-.105*LMB/LEN+1.0315)                     VOL 0046
      AVAA=AAVOM*P-RTAA                                                           VOL 0047
      DHV=.00223*LEN**3                                                           VOL 0048
      DHAA=DHV/8.5                                                                VOL 0049
      CN=(DAVG+LRD/LEN*8.5)*LEN*B                                                 VOL 0050
      RDHA=(AREADH+24.+.00225*CN+2.37*LEN)*1.09                                   VOL 0051
C     INCLUDES INPUTS, CO CABIN AND PILOT HOUSE WITH ALLOWANCE FOR PASSAGEWAYS    VOL 0052
      IF(RDHA.GT.DHAA) GO TO 1000                                                 VOL 0053
      TAAA=DHAA+AVAA                                                              VOL 0054
      ODA=2.12*LEN-232.                                                           VOL 0055
      IF(ODA.LT.0.) ODA=0.                                                        VOL 0056
      XMFDA=11.9*NAC+500.                                                         VOL 0057
      CSDA=4.23*NAC                                                               VOL 0058
      OSRDA=73.*NOFF                                                              VOL 0059
      OHDA=12.*NOFF                                                               VOL 0060
      CPODA=40.*NCPO                                                              VOL 0061
      CPOHDA=8.*NCPO                                                              VOL 0062
      CBDA=22.*NENL                                                               VOL 0063
      CHDA=5.*NENL                                                                VOL 0064
      CODA=2.37*LEN-76.                                                           VOL 0065
      CSTDA=300.+.021*D*NAC                                                       VOL 0066
      OSDA=.00719*CN                                                              VOL 0067
      WDA=.00314*CN-157.                                                          VOL 0068
      IF(WDA.LT.0.) WDA=0.                                                        VOL 0069
      RLDA=100.                                                                   VOL 0070
      CLDA=40.                                                                    VOL 0071
      UTDA=0.                                                                     VOL 0072
```

```
      IF(JOPT.EQ.2) GOTO 8                                                  VOL 0073
      UTDA=460.                                                             VOL 0074
      IF(MTYPE.EQ.1) UTDA=65.                                               VOL 0075
    8 SGDA=.0014*CN+150.                                                    VOL 0076
      ACDA=.00088*CN                                                        VOL 0077
      XICDA=.88*LEN+4.                                                      VOL 0078
      AMDA=.0485*CN                                                         VOL 0079
      PHDA=100.+.00225*CN                                                   VOL 0080
      TRAA=1.09*(AREADH+AREAHL+ODA+XMFDA+CSDA+OSRDA+OHDA+CPODA+CPOHDA+      VOL 0081
     1CBDA+CHDA+CODA+CSTDA+CSDA+WDA+RLDA+CLDA+UTDA+SGDA+ACDA+XICDA+AMDA+    VOL 0082
     2PHDA)                                                                 VOL 0083
      IF(TRAA.GT.TAAA) GOTO 10                                              VOL 0084
      DHSV=.0015I*LEN**3                                                    VOL 0085
      DHSAA=DHSV/8.5                                                        VOL 0086
      DHAMIN=AMAXI(DHSAA,RDHA)                                              VOL 0087
      TAAA=DHAMIN+AVAA                                                      VOL 0088
      IF(TRAA.GT.TAAA) GOTO 11                                              VOL 0089
   12 DHV=DHSV                                                              VOL 0090
      DHAA=DHV/8.5                                                          VOL 0091
      ENCVOL=DHV+THV                                                        VOL 0092
      RETURN                                                                VOL 0093
   11 DHAR=TRAA-AVAA                                                        VOL 0094
      DHSV=DHAR*8.5                                                         VOL 0095
      GOTO 12                                                               VOL 0096
   10 RHAA=TRAA-DHAA                                                        VOL 0097
      RDAA=RHAA-AVAA                                                        VOL 0098
      X1=RDAA/(8*LEN)                                                       VOL 0099
      IF(X1.GT..7) GOTO 1                                                   VOL 0100
      IF(X1.GT..2) GOTO 2                                                   VOL 0101
      LRD=-3.221*X1*X1+2.031*X1-.0184                                       VOL 0102
      GOTO 3                                                                VOL 0103
    1 LRD=.463*X1*X1+.446*X1+.22                                            VOL 0104
      GOTO 3                                                                VOL 0105
    2 LRD=X1+.059                                                           VOL 0106
    3 LRD=LRD*LEN                                                           VOL 0107
      DECKHT=8.5                                                            VOL 0108
```

```
      IF(ABS(LRD-LRD1).LT..05*LEN) GOTO 15                              VOL 0109
      IF(KNDEX.GT.20) GOTO 1000                                         VOL 0110
      KNDEX=KNDEX+1                                                     VOL 0111
      LRD1=LRD                                                          VOL 0112
      GOTO 13                                                           VOL 0113
   15 C1=.4*LEN                                                         VOL 0114
      C2=.6*LEN                                                         VOL 0115
      AVAA=RHAA                                                         VOL 0116
      IF(LRD.LT.C1.OR.LRD.GT.C2) GOTO 4                                 VOL 0117
      AVAA=AVAA+(C2-LRD)*8                                              VOL 0118
      RDAA=RDAA+(C2-LRD)*8                                              VOL 0119
      LRD=C2                                                            VOL 0120
    4 IF(LRD.GT.LEN) GOTO 1000                                          VOL 0121
      THV=THV+RDAA*8.5                                                  VOL 0122
      ENCVOL=DHV+THV                                                    VOL 0123
      RETURN                                                            VOL 0124
 1000 LEN=-1000.                                                        VOL 0125
      RETURN                                                            VOL 0126
      END                                                               VOL 0127
```

```
      SUBROUTINE SHEER(DMB,FC,F1C,F2O,DC,D1C,C2O,LEN,H,DECKHT)          SHER0001
      REAL LEN                                                         SHER0002
      D1O=.0025*LEN+DMB                                                SHER0003
      IF(D1O.LT.LEN/16.) D1C= LEN/16.                                  SHER0004
      FO=1.011827*(100.*H/LEN)-.000636215*LEN+2.780649                 SHER0005
      FO=LEN*FO/100.                                                   SHER0006
      FO=FO-DECKHT                                                     SHER0007
      DO=FO+H                                                          SHER0008
      F2O=.01*LEN*(2.125+.00125*LEN)                                   SHER0009
      D2O=F2O+H                                                        SHER0010
    7 SO=DO-D1O                                                        SHER0011
      RO=SO/LEN                                                        SHER0012
      IF(RO.LT..01) GCTO 1                                             SHER0013
      IF(RO.GT..03) GOTO 2                                             SHER0014
    6 S2O=D2O-D1O                                                      SHER0015
      R2O=S2O/LEN                                                      SHER0016
      IF(R2O.LT..001) GOTO 3                                           SHER0017
      IF(R2O.GT..0075) GOTO 4                                          SHER0018
      GOTC 5                                                           SHER0019
    1 SO=.01*LEN                                                       SHER0020
      DO=SO+D1O                                                        SHER0021
      GOTC 6                                                           SHER0022
    2 SO=.03*LEN                                                       SHER0023
      D1O=DO-SO                                                        SHER0024
      GOTC 6                                                           SHER0025
    3 S2O=.OC1*LEN                                                     SHER0026
      D2O=D1O+S2O                                                      SHER0027
      GOTO 5                                                           SHER0028
    4 S2O=.0075*LEN                                                    SHER0029
      D1O=D2O-S2O                                                      SHER0030
      GOTO 7                                                           SHER0031
    5 FO=DO-H                                                          SHER0032
      F2O=D2C-H                                                        SHER0033
      F1O=D1O-H                                                        SHER0034
      RETURN                                                           SHER0035
      END                                                              SHER0036
```

```
      SUBROUTINE WEIGHT                                                 WGHT0001
      REAL LEN,NOFF,NCPO,NENL,NAC                                       WGHT0002
      COMMON/AA/D,NOFF,NCPO,NENL                                        WGHT0003
      COMMON/BB/CN,DHV,ENCVOL,DAVG,AREADH,AREAHL,LEN                    WGHT0004
      COMMON/CC/SHPM,SHPE,VSUS,VE,RF,DELCF,SFCM,SFCH,MTYPE,JOPT,PCM,PCE WGHT0005
      COMMON/DD/ELKW,AVGKW,ELOAD,BLOAD,PALOAD                           WGHT0006
      COMMON/LL/WTFUEL,WTLO,WTCREW,WTPE,WTPS,WCARGO,WTAMMO,WTAC,WACFUL  WGHT0007
      COMMON/VV/WT1M,WT111,WT112,WT113,WT2M,WT203,WT30C,WT301,WT3R,WT6I, WGHT0008
     1WT6II,WT6III,WT6IV                                                WGHT0009
      COMMON/WW/WTG1,WTG2,WTG3,WTG4,WTG5,WTG6,WTG7,WLSHIP,WFULLC,DBMAR  WGHT0010
      WT1M=.0016915*CN                                                  WGHT0011
      WT111=10.+.0013751*DHV                                            WGHT0012
      WT203=.56*LEN*(.0000159*SHPM+.0765)                               WGHT0013
      IF(JOPT.EQ.2) GOTO 1                                              WGHT0014
      IF(MTYPE.EQ.1) GOTO 2                                             WGHT0015
      WT2M=256.3-.0041*(7000.-SHPE)                                     WGHT0016
      IF(SHPE.GT.7000.) WT2M=256.3                                      WGHT0017
      GOTO 3                                                            WGHT0018
    2 WT2M=.0184615*SHPM+1.0385                                         WGHT0019
      GOTO 3                                                            WGHT0020
    1 WT2M=WTG2-WT203                                                   WGHT0021
    3 WT112=.1121*WT2M                                                  WGHT0022
      WT300=.054*ELKW                                                   WGHT0023
      IF(ELKW.GE.500.) WT300=41.54+.01068*ELKW                          WGHT0024
      IF(ELKW.GT.800.) WT300=5.38+.06748*ELKW                           WGHT0025
      WT301=.01335*ELKW                                                 WGHT0026
      WT3R=0.109*LEN                                                    WGHT0027
      VOL=ENCVOL/100000.                                                WGHT0028
      WTG5=-2.884*VOL*VOL+81.82*VOL                                     WGHT0029
      WT6I=.0001411*ENCVOL                                              WGHT0030
      NAC=NOFF+NCPO+NENL                                                WGHT0031
      WT6II=.001158*NAC*NAC+.5819*NAC                                   WGHT0032
      Q=NAC/15.+1.                                                      WGHT0033
      RAFTS=AINT(Q)                                                     WGHT0034
      BOATWT=1.4                                                        WGHT0035
      IF(NAC.GT.25.) BOATWT=5.                                          WGHT0036
```

```
      IF(NAC.GT.50.) BOATWT=10.1                                        WGHT0037
      WT6III=BOATWT+.2*RAFTS+.002*NAC                                   WGHT0038
      WT6IV=.00206*NAC*NAC+.20265*NAC                                   WGHT0039
      WTG6=WT6I+WT6II+WT6III+WT6IV                                      WGHT0040
      WTG3=WT300+WT301+WT32                                             WGHT0041
      WTG2=WT2M+WT203                                                   WGHT0042
      WTFDS=WTG3+WTG4+WTG5+WTG7                                         WGHT0043
      WT113=.0615*WTFDS                                                 WGHT0044
      WTG1=WT1M+WT111+WT112+WT113                                       WGHT0045
      WLSHIP=(WTG1+WTG2+WTG3+WTG4+WTG5+WTG6+WTG7)*DBMAR                 WGHT0046
      WTCREW=.0737*NAC                                                  WGHT0047
      WTPE=.105*NOFF+.0737*NCPO+.029*NENL                               WGHT0048
      WTPS=(.0222+.00202*D)*NAC+.00135*D*NAC+.186*NAC                   WGHT0049
      WFULLD=WLSHIP+WTCREW+WTPE+WTPS+WTLO+WTFUEL+WCARGO+WTAMMO+WTAC+    WGHT0050
     1WACFUL                                                            WGHT0051
      RETURN                                                            WGHT0052
      END                                                               WGHT0053
```

```
      SUBROUTINE VCG(CFULD)                                                  VCG 0001
      REAL LEN,LRD                                                           VCG 0002
      COMMON/AA/D,OFF,CPD,ENL                                                VCG 0003
      COMMON/BB/CN,DHV,ENCVOL,DAVG,AREACH,AREAHL,LEN                         VCG 0004
      COMMON/EE/GR4WT(20),GR4CG(20),GR7WT(20),GR7CG(20),AMOWT(20),           VCG 0005
     1AMOCG(20),ACWT(20),ACCG(20),CARGOW(20),CARGOC(20)                      VCG 0006
      COMMON/HH/CGFUEL,CGLO,CGCREW,CGPE,CGPS,CCARGO,CGAMMO,CGAC,CACFUL       VCG 0007
      COMMON/DD/CGG1,CGG2,CGG3,CGG4,CGG5,CGG6,CGG7,CLSHIP,CFULLD             VCG 0008
      COMMON/LL/WTFUEL,WTLO,WTCREW,WTPE,WTPS,WCARGO,WTAMMO,WTAC,WACFUL       VCG 0009
      COMMON/WW/WTG1,WTG2,WTG3,WTG4,WTG5,WTG6,WTG7,WLSHIP,WFULLD,DBMAR       VCG 0010
      COMMON/II/DO,D10MN,D20                                                 VCG 0011
      COMMON/JJ/DHM,XLM,LRD                                                  VCG 0012
      COMMON/VV/WT1M,WT111,WT112,WT113,WT2M,WT203,WT30C,WT301,WT3R,WT6I,      VCG 0013
     1WT6II,WT6III,WT6IV                                                     VCG 0014
      COMMON/FF/TITLE(5,40),HEAD(20),NOARM,NOELT                             VCG 0015
      CG1M=.55*DAVG                                                          VCG 0016
      HLEN=LEN/2.                                                            VCG 0017
      D10=D10MN                                                              VCG 0018
      IF(LRD.GE.HLEN) D10=D10MN+8.5                                          VCG 0019
      CG111=1.4*D10                                                          VCG 0020
      CG112=.2*D10                                                           VCG 0021
      CG2M=.54*D10MN                                                         VCG 0022
      CG203=.16*D10                                                          VCG 0023
      CG300=.7*D10                                                           VCG 0024
      CG301=.8*D10                                                           VCG 0025
      CG3R=D10                                                               VCG 0026
      CGG5=.71*D10                                                           VCG 0027
      CG6I=.75*D10                                                           VCG 0028
      CG6II=D10                                                              VCG 0029
      CG6III=1.6*D10MN                                                       VCG 0030
      CG6IV=.84*D10                                                          VCG 0031
      G4MOM=0.                                                               VCG 0032
      DO1 I=1,NOELT                                                          VCG 0033
    1 G4MOM=G4MOM+GR4WT(I)*GR4CG(I)                                          VCG 0034
      CGG4=0.                                                                VCG 0035
      IF(G4MOM.GT.1.) CGG4=G4MOM/WTG4*D10MN                                  VCG 0036
```

```
      ACMOM=0.                                                          VCG 0037
      G7MOM=0.                                                          VCG 0038
      AMOMOM=0.                                                         VCG 0039
      CGOMOM=0.                                                         VCG 0040
      DO 2 I=1,NOARM                                                    VCG 0041
      ACMOM=ACMOM+ACWT(I)*ACCG(I)                                       VCG 0042
      G7MOM=G7MOM+GR7WT(I)*GR7CG(I)                                     VCG 0043
      AMOMOM=AMOMOM+AMOWT(I)*AMOCG(I)                                   VCG 0044
    2 CGOMOM=CGOMOM+CARGOW(I)*CARGOC(I)                                 VCG 0045
      CGG7=0.                                                           VCG 0046
      IF(G7MOM.GT.1.) CGG7=G7MOM*D10MN/WTG7                             VCG 0047
      CCARGO=0.                                                         VCG 0048
      IF(CGOMOM.GT.1.) CCARGO=CGOMOM/WCARGO*D10MN                       VCG 0049
      CGAC=0.                                                           VCG 0050
      IF(ACMOM.GT.1.) CGAC=ACMOM*D10MN/WTAC                             VCG 0051
      CGAMMO=0.                                                         VCG 0052
      IF(AMOMOM.GT.1.) CGAMMO=AMOMOM*D10MN/WTAMMO                       VCG 0053
      CACFL=CACFUL*D10MN                                                VCG 0054
      CGG3=(CG300*WT300+CG301*WT301+CG3R*WT3R)/WTG3                     VCG 0055
      CGG6=(CG6I*WT6I+CG6II*WT6II+CG6III*WT6III+CG6IV*WT6IV)/WTG6       VCG 0056
      CGG2=(CG2M*WT2M+CG203*WT203)/WTG2                                 VCG 0057
      CG113=.87*(CGG3*WTG3+CGG4*WTG4+CGG5*WTG5+CGG7*WTG7)/(WTG3+WTG4+   VCG 0058
     1WTG5+WTG7)                                                        VCG 0059
      CGG1=(CG1M*WT1M+CG111*WT111+CG112*WT112+CG113*WT113)/WTG1         VCG 0060
      CLSHIP=(CGG1*WTG1+CGG2*WTG2+CGG3*WTG3+CGG4*WTG4+CGG5*WTG5+CGG6*   VCG 0061
     1WTG6+CGG7*WTG7)*DBMAR/WLSHIP                                      VCG 0062
      CGFUEL=.3*D10                                                     VCG 0063
      CGLO=.13*D10MN                                                    VCG 0064
      CGCREW=.97*D10MN                                                  VCG 0065
      CGPE=CGCREW                                                       VCG 0066
      CGPW=.26*D10                                                      VCG 0067
      CGGS=.85*D10MN                                                    VCG 0068
      CGPV=.55*D10                                                      VCG 0069
      CGPS=((.0222+.00202*D)*CGPV+.00135*D*CGGS+.186*CGPW)/(.2082+.00337 VCG 0070
     1*D)                                                               VCG 0071
      XLDMOM=(CGFUEL*WTFUEL+CGLO*WTLO+CGCREW*WTCREW+CGPE*WTPE+CGPS*WTPS VCG 0072
```

```
1+CCARGO*WCARGO+CGAMMO*WTAMMO+CGAC*WTAC+CACFL *WACFUL)                  VCG 0073
 CFULLD=(CLSHIP*WLSHIP+XLDMOM)/WFULLD                                  VCG 0074
 CFULLD=CFULLD                                                         VCG 0075
 RETURN                                                                VCG 0076
 END                                                                   VCG 0077
```

```
      SUBROUTINE COST(LEN)                                                    COST0001
      REAL MCST                                                               COST0002
      REAL LEN,LABCST,MATCST,LOA                                              COST0003
      COMMON/CC/SHPM,SHPE,VSUS,VE,PE,DELCF,SFCM,SFCH,MTYPE,JOPT,PCM,PCF       COST0004
      COMMON/MM/CSTG1,CSTG2,CSTG3,CSTG4,CSTG5,CSTG6,CSTG7,DCST,CCST,MCST      COST0005
      COMMON/NN/ DOLHR,G1IND,G2IND,G3IND,G5IND,G6IND,TOTCST                   COST0006
      COMMON/WW/WTG1,WTG2,WTG3,WTG4,WTG5,WTG6,WTG7,WLSHIP,WFULLD,DBMAR        COST0007
      W1=WTG1*DBMAR                                                           COST0008
      W2=WTG2*DBMAR                                                           COST0009
      W3=WTG3*DBMAR                                                           COST0010
      W4=WTG4*DBMAR                                                           COST0011
      W5=WTG5*DBMAR                                                           COST0012
      W6=WTG6*DBMAR                                                           COST0013
      W7=WTG7*DBMAR                                                           COST0014
      G1MH=10.**(ALOG10(W1)*.75217+2.97276)                                   COST0015
      G2MH=10.**(ALOG10(W2)*1.0273+2.3437)                                    COST0016
      G3MH=10.**(ALOG10(W3)*1.07776+2.62981)                                  COST0017
      G4MH=10.**(ALOG10(W4)*1.07776+2.62981)                                  COST0018
      G5MH=10.**(ALOG10(W5)*.763428+3.2366)                                   COST0019
      G6MH=10.**(ALOG10(W6)*.9742+2.74181)                                    COST0020
      G7MH=10.**(ALOG10(W7)*.75217+2.97276)                                   COST0021
      G1MC=10.**(ALOG10(W1)*.954243+2.790484)                                 COST0022
      G2MC=CSTG2                                                              COST0023
      IF(JOPT.EQ.2) GOTO 1                                                    COST0024
      G2MC=10.**(ALOG10(W2)*1.018885+3.634328)                                COST0025
      IF(MTYPE.EQ.2) G2MC=G2MC+1500000.                                       COST0026
    1 G3MC=10.**(ALOG10(W3)*1.072551+3.667812)                                COST0027
      G4MC=CSTG4                                                              COST0028
      G5MC=10.**(ALOG10(W5)*.870906+3.974192)                                 COST0029
      G6MC=10.**(ALOG10(W6)*1.068265+3.603833)                                COST0030
      G7MC=CSTG7                                                              COST0031
      G1LC=G1MH*DOLHR*1.98                                                    COST0032
      G2LC=G2MH*DOLHR*1.98                                                    COST0033
      G3LC=G3MH*DOLHR*1.98                                                    COST0034
      G4LC=G4MH*DOLHR*1.98                                                    COST0035
      G5LC=G5MH*DOLHR*1.98                                                    COST0036
```

```
      G6LC=G6MH*DOLHR*1.98                                                    COST0037
      G7LC=G7MH*DOLHR*1.98                                                    COST0038
      G1MC=G1MC*G1IND*1.1                                                     COST0039
      IF(JOPT.EQ.2) GOTO 2                                                    COST0040
      G2MC=G2MC*G2IND                                                         COST0041
    2 G3MC=G3MC*G3IND*1.1                                                     COST0042
      G5MC=G5MC*G5IND*1.1                                                     COST0043
      G6MC=G6MC*G6IND*1.1                                                     COST0044
      G2MC=G2MC*1.1                                                           COST0045
      G4MC=G4MC*1.1                                                           COST0046
      G7MC=G7MC*1.1                                                           COST0047
      LABCST=G1LC+G2LC+G3LC+G4LC+G5LC+G6LC+G7LC                               COST0048
      MATCST=G1MC+G2MC+G3MC+G4MC+G5MC+G6MC+G7MC                               COST0049
      LOA=1.08*LEN                                                            COST0050
      FACTOR=(.114*LCA-1.6)/100.                                              COST0051
      DLC=FACTOR*LABCST                                                       COST0052
      FACTOR=(-.01*LOA+7.5)/100.                                              COST0053
      DMC=FACTOR*MATCST                                                       COST0054
      FACTOR=(.014*LOA+7.)/100.                                               COST0055
      CLC=FACTOR*LABCST                                                       COST0056
      FACTOR=(-.015*LOA+6.5)/100.                                             COST0057
      CMC=FACTOR*MATCST                                                       COST0058
      TOTCST=LABCST+MATCST+DLC+DMC+CLC+CMC                                    COST0059
      ORICST=.02*TOTCST                                                       COST0060
      SPARES=(.09*G2MC+.08*G3MC+.25*G4MC+.1*G5MC)/1.1                         COST0061
      RETRO=.04*TOTCST                                                        COST0062
      ADMIN=.035*TOTCST                                                       COST0063
      CSTG1=G1LC+G1MC                                                         COST0064
      CSTG2=G2LC+G2MC                                                         COST0065
      CSTG3=G3LC+G3MC                                                         COST0066
      CSTG4=G4LC+G4MC                                                         COST0067
      CSTG5=G5LC+G5MC                                                         COST0068
      CSTG6=G6LC+G6MC                                                         COST0069
      CSTG7=G7LC+G7MC                                                         COST0070
      DCST=DLC+DMC                                                            COST0071
      CCST=CLC+CMC                                                            COST0072
```

```
MCST=ORICST+SPARES+RETRO+ADMIN                                    COST0073
TOTCST=TOTCST+MCST                                                COSTC074
RETURN                                                            COSTC075
END                                                               COSTC076
```

```
      SUBROUTINE SEASPD(AVSP)                                                  SEAS0001
      REAL LEN,KGTRY,KY,IY,JY,IYY                                              SEAS0002
      COMMON/BB/ CN,DEV,ENGVOL,DAVG,AREADH,AREAHL,LEN                          SEAS0003
      COMMON/CC/SHPM,SHPE,VSUS,VE,RE,DELCF,SFCM,SFCH,MTYPE,JOPT,PCM,PCE        SEAS0004
      COMMON/GG/FRSC,CP,CX,GMMUL,KGTRY,DPTRY,B,H,CWP                           SEAS0005
      KY=.24                                                                   SEAS0006
      G=32.155                                                                 SEAS0007
      R=1.9905                                                                 SEAS0008
      PI=3.14159                                                               SEAS0009
      IY=(KY*LEN)**2*2240.*DPTRY/G                                             SEAS0010
      CIL=.14210526*CWP-.063568                                                SEAS0011
      JY=CIL*B*LEN**3                                                          SEAS0012
      C=H                                                                      SEAS0013
      B1=B/2.                                                                  SEAS0014
      A=LEN/2.                                                                 SEAS0015
      BCC=B1/C+1.19-(1.64-.86666697E-1*A/B1+.625E-2*(A/B1)**2-.20833346E       SEAS0016
     1-3*(A/B1)**3)                                                            SEAS0017
      YYK1=.66302837E-1+.5773045*BCC+.31592344*BCC**2-.15287906*BCC**3         SEAS0018
     1+.028399747*BCC**4                                                       SEAS0019
      IF(CX-.814)1,2,3                                                         SEAS0020
    3 CXP=(CX-.814)*.81395                                                     SEAS0021
      CXH=(CX-.814)*.60465                                                     SEAS0022
      GOTO 4                                                                   SEAS0023
    2 CXP=0.                                                                   SEAS0024
      CXH=0.                                                                   SEAS0025
      GOTO 4                                                                   SEAS0026
    1 CXP=0.                                                                   SEAS0027
      CXH=(CX-.814)*.27193                                                     SEAS0028
    4 FKYY=.6051                                                               SEAS0029
      CPP=(CP-.58)*2.76666                                                     SEAS0030
      CSP=FKYY+CPP+CXP                                                         SEAS0031
      IYY=YYK1*CSP/120.*PI*R*LEN*B*H*(LEN*LEN+4.*H*H)                          SEAS0032
      TP=2.*PI*((IY+IYY)/(G*R*JY))**.5                                         SEAS0033
      ZK1=1.9+(B1/C-2.)/1.05                                                   SEAS0034
      FKZ=.599                                                                 SEAS0035
      CPH=(CP-.58)*1.41666                                                     SEAS0036
```

```
      CSH=FKZ+CPH+CXH                                                    SEAS0037
      SM=2240.*DPTRY/G                                                   SEAS0038
      AWP=CWP*LEN*B                                                      SEAS0039
      ZM=CSH*ZK1*PI*R*LEN*B*H/6.                                         SEAS0040
      TH=6.28318*SQRT((SM+ZM)/(G*R*AWP))                                 SEAS0041
      TPL=TP/(SQRT(LEN))                                                 SEAS0042
      THL=TH/(SQRT(LEN))                                                 SEAS0043
      T=TPL                                                              SEAS0044
      IF(THL.GT.TPL) T=THL                                               SEAS0045
      VLR=(.9025/T-SQRT(.95*G/(2.*PI)))/1.6878                           SEAS0046
      WAVEH=.0256465*LEN                                                 SEAS0047
      W=DPTRY/(100.*(.01*LEN)**3)                                        SEAS0048
      WW=(11.*W*W-8.25281*W+3.86439)/6000.                               SEAS0049
      VRT=16.*H/LEN+.60293*W-.15617+WW*LEN                               SEAS0050
      VLR=VRT*VLR                                                        SEAS0051
      SPEED=VLR*SQRT(LEN)                                                SEAS0052
      IF(SPEED.LT.VSUS) GOTO 6                                           SEAS0053
      PER1=100.                                                          SEAS0054
      GOTO 5                                                             SEAS0055
    6 IF(WAVEH.LT.8.) GOTO 7                                             SEAS0056
      IF(WAVEH.LT.13.) GOTO 8                                            SEAS0057
      PER1=-40.49996+14.949994*WAVEH-.54333305*WAVEH**2+.66666623E-2*    SEAS0058
     1WAVEH**3                                                           SEAS0059
      GOTO 5                                                             SEAS0060
    8 PER1=-126.00002+21.933338*WAVEH-.25625043*WAVEH**2-.017708321*     SEAS0061
     1WAVEH**3                                                           SEAS0062
      GOTO 5                                                             SEAS0063
    7 PER1=-.89785317E-7+.14285863*WAVEH-.13333482*WAVEH**2+.037500399*  SEAS0064
     1WAVEH**3+.29761609E-2*WAVEH**4                                     SEAS0065
    5 PER2=(100.-PER1)/2.                                                SEAS0066
      PER=100.-PER2                                                      SEAS0067
      AVSP=(PER*VSUS+PER2*SPEED)/100.                                    SEAS0068
      RETURN                                                             SEAS0069
      END                                                                SEAS0070
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      SUBROUTINE OUTPLT(AVSP,EXCKG,I1)                                  OUTP0001
      REAL LEN,NOFF,NCPO,NENL,KGTRY                                     OUTP0002
      REAL LRO                                                          OUTP0003
      REAL MCST                                                         OUTP0004
      COMMON/AA/O,NOFF,NCPO,NENL                                        OUTP0005
      COMMON/BB/CN,DHV,ENCVOL,DAVG,AREADH,AREAHL,LEN                    OUTP0006
      COMMON/CC/SHPM,SHPE,VSUS,VE,RE,DELCF,SFCM,SFCH,MTYPE,JCPT,PCM,PCE OUTP0007
      COMMON/DD/ELKW,AVGKW,ELOAD,BLOAD,PALOAD                           OUTP0008
      COMMON/EE/GR4WT(20),GR4CG(20),GR7WT(20),GR7CG(20),AMOWT(20),AMOCG OUTP0009
     1(20),ACWT(20),ACCG(20),CARGOW(20),CARGOC(20)                      OUTP0010
      COMMON/FF/ TITLE(5,40),HEAD(20),NOARM,NCELT                       OUTP0011
      COMMON/GG/ERSC,CP,CX,GMMUL,KGTRY,DPTRY,B,H,CWP                    OUTP0012
      COMMON/HH/CGFUEL,CGLO,CGCREW,CGPE,CGPS,CCARGO,CGAMMO,CGAC,CACFUL  OUTP0013
      COMMON/II/DO,D10,D20                                              OUTP0014
      COMMON/JJ/DHM,XLM,LRO                                             OUTP0015
      COMMON/KK/ELLD(20),DHAR(20),HLAR(20),ELD(20),DHA(20),HLA(20),     OUTP0016
     1GR7CST(20),GR4CST(20)                                             OUTP0017
      COMMON/LL/WTFUEL,WTLO,WTCREW,WTPE,WTPS,WCARGO,WTAMMO,WTAC,WACFUL  OUTP0018
      COMMON/MM/CSTG1,CSTG2,CSTG3,CSTG4,CSTG5,CSTG6,CSTG7,DCST,CCST,MCST OUTP0019
      COMMON/NN/ DOLHR,G1IND,G2IND,G3IND,G5IND,G6IND,TOTCST             OUTP0020
      COMMON/OO/CGG1,CGG2,CGG3,CGG4,CGG5,CGG6,CGG7,CLSHIP,CFULLD        OUTP0021
      COMMON/PP/VMB,TANKVL,AVAA,DHAA,ODA,XMFDA,CSDA,OSRDA,OHDA,CPODA,   OUTP0022
     1CPOHDA,CBDA,CHDA,CODA,CSTDA,OSDA,WDA,RLDA,CLDA,UTDA,SGDA,ACDA,XICD OUTP0023
     2A,AMDA,PHDA                                                       OUTP0024
      COMMON/WW/WTG1,WTG2,WTG3,WTG4,WTG5,WTG6,WTG7,WLSHIP,WFULLD,DBMAR  OUTP0025
      WRITE(5,100) HEAD                                                 OUTP0026
  100 FORMAT('1',20A4/)                                                 OUTP0027
      WRITE(5,101)                                                      OUTP0028
  101 FORMAT(T30,'*****INPUT DATA*****'//' ARMAMENT, AIRCRAFT AND CARGO OUTP0029
     1INPUTS'//,T9,'ITEM',T26,'CARGO   CARGO  GROUP 7 GROUP 7  AMMO',T66 OUTP0030
     2,'AMMO  AIRCRAFTAIRCRAFT  ELECT  AREA IN AREA IN GROUP 7'/,T25,    OUTP0031
     3'WEIGHT    VCG   WEIGHT    VCG   WEIGHT   VCG    WEIGHT   VCG',T90 OUTP0032
     4,'LOAD  DECKHSE   HULL    COST'/)                                  OUTP0033
      WRITE(5,102)((TITLE(J,I),J=1,5),CARGOW(I),CARGOC(I),GR7WT(I),GR7CG OUTP0034
     1(I),AMOWT(I),AMOCG(I),ACWT(I),ACCG(I),ELLD(I),DHAR(I),HLAR(I),    OUTP0035
     2GR7CST(I),I=1,NOARM)                                              OUTP0036
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102 FORMAT(' ',5A4,F8.1,F8.3,F8.1,F8.3,F8.1,F8.3,F8.1,F8.3,F9.3,F8.0,      OUTP0037
   1F8.0,F8.0)                                                             OUTP0038
    WRITE(5,103)                                                           OUTP0039
103 FORMAT(/' ELECTRONICS INPUT'//T9,'ITEM',T24,'GROUP 4 GROUP 4',T41,     OUTP0040
   1'ELECT  AREA IN AREA IN GROUP 4'/,T24,'WEIGHT   VCG     LOAD',T48,     OUTP0041
   2'DECKHSE  HULL    COST'/)                                             OUTP0042
    WRITE(5,104)((TITLE(J,I+20),J=1,5),GR4WT(I),GR4CG(I),ELC(I),DHA(I)     OUTP0043
   1,HLA(I),GR4CST(I),I=1,NOELT)                                           OUTP0044
104 FORMAT(' ',5A4,F8.1,2F8.3,3F8.0)                                       OUTP0045
    WRITE(5,105)                                                           OUTP0046
105 FORMAT(/' MANNING INPUT'/)                                             OUTP0047
    WRITE(5,106) NOFF,NCPO,NENL                                            OUTP0048
106 FORMAT('  NO. OF OFFICERS = ',F5.0,5X,'NO. OF CPOS = ',F5.0,5X,       OUTP0049
   1'NO. OF ENLISTED MEN = ',F5.0,/)                                       OUTP0050
    WRITE(5,121)                                                           OUTP0051
121 FORMAT(' COST INDICES INPUT'/)                                         OUTP0052
    WRITE(5,119) DOLHR,G1IND,G2IND,G3IND,G5IND,G6IND                       OUTP0053
119 FORMAT('  LABOR RATE = ',F5.2,' DOLLARS/HR'/'  GROUP 1 INDEX = ',      OUTP0054
   1F5.2/'  GROUP 2 INDEX = ',F5.2/'  GROUP 3 INDEX = ',F5.2/'  GROUP     OUTP0055
   25 INDEX = ',F5.2/'  GROUP 6 INDEX = ',F5.2/)                           OUTP0056
    WRITE(5,120)                                                           OUTP0057
120 FORMAT('       INDICES INCLUDE EFFECTS OF INFLATION AND SPECIAL MAT    OUTP0058
   1ERIAL COSTS'/)                                                         OUTP0059
    WRITE(5,107)                                                           OUTP0060
107 FORMAT(' MILITARY MISSION CONSUMABLES INPUT'/)                         OUTP0061
    WRITE(5,108) D,WACFUL,CACFUL                                           OUTP0062
108 FORMAT('  NO. ENDURANCE DAYS = ',F5.0,'  WEIGHT AIRCRAFT FUEL = ',     OUTP0063
   1F7.1,'  VCG AIRCRAFT FUEL = ',F8.3)                                     OUTP0064
    DBMAR=DBMAR-1.                                                         OUTP0065
    WRITE(5,109)                                                           OUTP0066
109 FORMAT(/,' VEHICLE PERFORMANCE INPUT')                                 OUTP0067
    IF(JOPT.EQ.2) GOTO 2                                                   OUTP0068
    WRITE(5,110) VSUS,VE,RE,PCE,PCM                                        OUTP0069
110 FORMAT(/'  MAX SUSTAINED SHP COMPUTED'/,' SUSTAINED SPEED = ',F8.2     OUTP0070
   1,' KTS'/,' ENDURANCE SPEED = ',F8.2,' KTS'/,' ENDURANCE RANGE = ',     OUTP0071
   2F8.0,' MILES'/,' PROP COEF ENDURANCE = ',F5.3,/,' PROP COEF MAXIMU     OUTP0072
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   3M = ',F5.3,/)                                                          OUTP0073
    GOTO 3                                                                 OUTP0074
  2 WRITE(5,111) SHPM,DHM,XLM,WTG2,SFCM,SFCH,VE,RE,PALCAD,PCE,PCM,         OUTP0075
   1CSTG2,WTLC                                                             OUTP0076
111 FORMAT('  MAX SUSTAINED SPEED COMPUTED'/,' MAX SUSTAINED SHP = ',      OUTP0077
   1F8.0,/,' MIN DECKHEIGHT FOR MACHINERY = ',F5.2,' FT'/,' MIN LENGTH     OUTP0078
   2 OF MACHINERY BOX = ',F6.2,' FT'/,' GROUP 2 WEIGHT = ',F8.1,' TONS     OUTP0079
   3'/,' SFC MAX POWER = ',F5.3,' LBS/SHP-HR'/,' SFC HALF POWER = ',       OUTP0080
   4F5.3,' LBS/SHP-HR'/,' ENDURANCE SPEED = ',F8.2,' KTS'/,' ENDURANCE     OUTP0081
   5 RANGE = ',F8.0,' MILES'/,' PROP AUX ELECT LOAD = ',F8.3,' KW'/,       OUTP0082
   6' PROP COEF ENDURANCE = ',F5.3,/' PROP COEF MAXIMUM = ',F5.3,/,        OUTP0083
   7' GROUP 2 COST = ',F9.0,' DOLLARS'/,' WEIGHT OF LUB OIL = ',F8.1,      OUTP0084
   8' TONS'/)                                                              OUTP0085
  3 WRITE(5,112) MTYPE,FRSC,GMMUL,DBMAR,DELCF,LEN,CP,CX                    OUTP0086
112 FORMAT('  OPTIONS'//,' MTYPE = ',I2,/,' FREE SURFACE CORRECTION =      OUTP0087
   1',F5.2,' FT',/,' GM MULTIPLIER = ',F5.3,/,' DESIGN AND BUILDERS MA     OUTP0088
   2RGIN = ',F5.3,/,' DELTA CF = ',F8.5,/,' LENGTH = ',F5.1, ' FT',/       OUTP0089
   3,' CP = ',F5.3,/,' CX = ',F5.3,/)                                      OUTP0090
    IF(I1.EQ.1) RETURN                                                     OUTP0091
    DAVG=DAVG+LRD/LEN*8.5                                                  OUTP0092
    WRITE(5,113)                                                           OUTP0093
113 FORMAT(//,T33,'*****OUTPUT*****'//,'  LENGTH  BEAM   DRAFT  DO        OUTP0094
   1D10   D20   DAVG  LNTH RD  CP    CX  DISPLACEMENT  SHPMAX    VSUS     OUTP0095
   2  SHPEND'/)                                                           OUTP0096
    WRITE(5,114)LEN,B,H,DO,D10,D20,DAVG,LRD,CP,CX,DPTRY,SHPM,VSUS,SHPE     OUTP0097
114 FORMAT(' ',F6.1,F8.2,F7.2,4F6.2,F9.1,2F6.3,F9.1,F11.0,F8.2,F9.0)       OUTP0098
    WRITE(5,160) AVSP                                                      OUTP0099
160 FORMAT(/,' AVERAGE SPEED IN SEAWAY IS ',F5.2,' KNOTS'/)                OUTP0100
    VOL=ENCVOL-DHV                                                         OUTP0101
    WRITE(5,115) ELKW                                                      OUTP0102
115 FORMAT(/,' ELECTRIC PLANT CAPACITY/GEN = ',F8.0,' KW'/)                OUTP0103
    FFF=1.+DBMAR                                                           OUTP0104
    R1=WTG1/WFULLD*FFF                                                     OUTP0105
    R2=WTG1/WLSHIP*FFF                                                     OUTP0106
    R3=WTG2/WFULLD*FFF                                                     OUTP0107
    R4=WTG2/WLSHIP*FFF                                                     OUTP0108
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      R5=WTG3/WFULLD*FFF                                                    OUTP0109
      R6=WTG3/WLSHIP*FFF                                                    OUTP0110
      R7=WTG4/WFULLD*FFF                                                    OUTP0111
      R8=WTG4/WLSHIP*FFF                                                    OUTP0112
      R9=WTG5/WFULLD*FFF                                                    OUTP0113
      R10=WTG5/WLSHIP*FFF                                                   OUTP0114
      R11=WTG6/WFULLD*FFF                                                   OUTP0115
      R12=WTG6/WLSHIP*FFF                                                   OUTP0116
      R13=WTG7/WFULLD*FFF                                                   OUTP0117
      R14=WTG7/WLSHIP*FFF                                                   OUTP0118
      R15=WLSHIP/WFULLD                                                     OUTP0119
      R16=1.                                                                OUTP0120
      WRITE(5,116)WTG1,CGG1,R1,R2,CSTG1,WTG2,CGG2,R3,R4,CSTG2,WTG3,CGG3,    OUTP0121
     1R5,R6,CSTG3,WTG4,CGG4,R7,R8,CSTG4,WTG5,CGG5,R9,R10,CSTG5,WTG6,CGG6    OUTP0122
     2,R11,R12,CSTG6,WTG7,CGG7,R13,R14,CSTG7,WLSHIP,CLSHIP,R15,R16,TOTCS    OUTP0123
     3T                                                                     OUTP0124
  116 FORMAT(/' ',8X,'WEIGHTS      VCG      WT/WFULLD   WT/WLSHIP     CO    OUTP0125
     1ST'//' WTG1',F10.1,3F12.3,F12.0/' WTG2',F10.1,3F12.3,F12.0/' WTG3'    OUTP0126
     2,F10.1,3F12.3,F12.0/' WTG4',F10.1,3F12.3,F12.0/' WTG5',F10.1,3F12.    OUTP0127
     33,F12.0/' WTG6',F10.1,3F12.3,F12.0/' WTG7',F10.1,3F12.3,F12.0//,      OUTP0128
     4' WLSHIP',F8.1,3F12.3,F12.0,' = TOTAL COST'/)                         OUTP0129
      R1=WTFUEL/WFULLD                                                      OUTP0130
      R2=WTLO/WFULLD                                                        OUTP0131
      R3=WTCREW/WFULLD                                                      OUTP0132
      R4=WTPE/WFULLD                                                        OUTP0133
      R5=WTPS/WFULLD                                                        OUTP0134
      R6=WCARGO/WFULLD                                                      OUTP0135
      R7=WTAMMO/WFULLD                                                      OUTP0136
      R8=WTAC/WFULLD                                                        OUTP0137
      R9=WACFUL/WFULLD                                                      OUTP0138
      CACFL=CACFUL*D10                                                      OUTP0139
      WRITE(5,117)WTFUEL,CGFUEL,R1,WTLO,CGLO,R2,WTCREW,CGCREW,R3,WTPE,      OUTP0140
     1CGPE,R4,WTPS,CGPS,R5,WCARGO,CCARGO,R6,WTAMMO,CGAMMO,R7,WTAC,CGAC,     OUTP0141
     2R8,WACFUL,CACFL,R9,WFULLD,CFULLD                                      OUTP0142
  117 FORMAT(' FUEL',F10.1,2F12.3/' LUB OIL',F7.1,2F12.3/' CREW',F10.1,     OUTP0143
     12F12.3/' PER EFF',F7.1,2F12.3/' PER STR',F7.1,2F12.3/' CARGO',F9.1    OUTP0144
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     2,2F12.3/' AMMO',F10.1,2F12.3/' AIR CFT',F7.1,2F12.3/' A/C FUEL',      OUTP0145
     3F6.1,2F12.3//' WELLD',F9.1,F12.3//)                                   OUTP0146
      WRITE(5,122) EXCKG                                                    OUTP0147
  122 FORMAT(' A MARGIN ON KG OF ',F6.3,' FT EXISTS ABOVE THE FULL LOAD      OUTP0148
     1KG VALUE GIVEN '//)                                                   OUTP0149
      WRITE(5,118) DCST,CCST,MCST                                           OUTP0150
  118 FORMAT(' NOTE   D&R MARGIN INCLUDED IN WLSHIP AND COST ESTIMATES B     OUTP0151
     1UT NOT IN INDIVIDUAL WEIGHT GROUPS'/'        OVERHEAD AND PROFIT A     OUTP0152
     2RE INCLUDED IN INDIVIDUAL WEIGHT GROUP COSTS'/'        TOTAL COST      OUTP0153
     3INCLUDES A DESIGN COST OF',F12.0,' DOLLARS'/' ',19X,'A CONST SERVI     OUTP0154
     4CES COST OF',F12.0,' DOLLARS'/' ',19X,'AND A MISC. ITEM COST OF',      OUTP0155
     5F12.0,' DOLLARS'/'        MISC.ITEM COST INCLUDES CRI OUTFIT, SPAR     OUTP0156
     6ES, RETROFIT COSTS, AND ADMINISTRATIVE COSTS(RIO)'/)                   OUTP0157
      WRITE(5,123) VOL,DHV                                                  OUTP0158
  123 FORMAT(/,' VOLUME OF HULL = ',F10.0,' CU FT'/,' VOLUME OF DECKHOUS    OUTP0159
     1E = ',F10.0,' CU FT'/)                                                OUTP0160
      AAVOM=VOL-VMB-TANKVL+DHV                                              OUTP0161
      R1=VMB/ENCVOL                                                         OUTP0162
      R2=TANKVL/ENCVOL                                                      OUTP0163
      R3=AAVOM/ENCVOL                                                       OUTP0164
      WRITE(5,124)VMB,R1,TANKVL,R2,AAVOM,R3                                 OUTP0165
  124 FORMAT(/,T26,'VOLUME(CU FT)     VOL/ENCVOL'//' MACHINERY ROOM',T28    OUTP0166
     1,F10.0,F15.3/' TANKAGE',T28,F10.0,F15.3/' ARRANGEMENTS',T28,F10.0,    OUTP0167
     2F15.3/)                                                               OUTP0168
      AR=AVAA+DHAA                                                          OUTP0169
      WRITE(5,125) AR,AVAA,DHAA                                             OUTP0170
  125 FORMAT(/' TOTAL ARRANGEMENTS AREA = ',F8.0/' HULL ARRANGEMENTS ARE    OUTP0171
     1A = ',F8.0/' DECKHOUSE ARRANGEMENTS AREA = ',F8.0/)                   OUTP0172
      WRITE(5,126)                                                          OUTP0173
  126 FORMAT(' ',T30,'AREA(SQ FT)  AREA/TOT AREA'/)                         OUTP0174
      R4=ODA/AR                                                             OUTP0175
      R5=XMFDA/AR                                                           OUTP0176
      R6=CSDA/AR                                                            OUTP0177
      R7=OSRDA/AR                                                           OUTP0178
      R8=OHDA/AR                                                            OUTP0179
      WRITE(5,127)ODA,R4,XMFDA,R5,CSDA,R6,OSRDA,R7,OHDA,R8                  OUTP0180
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127 FORMAT(' OFFICE SPACE',T30,F10.0,F13.3,/' MESSING FACILITIES',T30,          OUTP0181
   1F10.0,F13.3/' CREW SPECIAL',T30,F10.0,F13.3/' OFFICER S.R.',T30,           OUTP0182
   2F10.0,F13.3/' OFFICER SANITARY',T30,F10.0,F13.3)                           OUTP0183
    R4=CPODA/AR                                                                OUTP0184
    R5=CPOHDA/AR                                                               OUTP0185
    R6=CBDA/AR                                                                 OUTP0186
    R7=CHDA/AR                                                                 OUTP0187
    R8=CCDA/AR                                                                 OUTP0188
    WRITE(5,128)CPODA,R4,CPOHDA,R5,CBDA,R6,CHDA,R7,CODA,R8                     OUTP0189
128 FORMAT(' CPO S.R.',T30,F10.0,F13.3/' CPO SANITARY',T30,F10.0,F13.3         OUTP0190
   1/' CREW BERTHING',T30,F10.0,F13.3/' CREW SANITARY',T30,F10.0,F13.3         OUTP0191
   2/' C.O. S.R.,CABIN & PANTRY',T30,F10.0,F13.3)                              OUTP0192
    R4=CSTDA/AR                                                                OUTP0193
    R5=OSDA/AR                                                                 OUTP0194
    R6=WDA/AR                                                                  OUTP0195
    R7=RLDA/AR                                                                 OUTP0196
    R8=CLDA/AR                                                                 OUTP0197
    WRITE(5,129)CSTDA,R4,OSDA,R5,WDA,R6,RLDA,R7,CLDA,R8                        OUTP0198
129 FORMAT(' COMMISSARY STORES',T30,F10.0,F13.3/' OTHER STORES',T30,            OUTP0199
   1F10.0,F13.3/' WORKSHOPS',T30,F10.0,F13.3/' REPAIR LOCKERS',T30,            OUTP0200
   2F10.0,F13.3/' CHAIN LOCKER',T30,F10.0,F13.3)                               OUTP0201
    R4=UTDA/AR                                                                 OUTP0202
    R5=SGDA/AR                                                                 OUTP0203
    R6=ACDA/AR                                                                 OUTP0204
    R7=XICDA/AR                                                                OUTP0205
    R8=AMDA/AR                                                                 OUTP0206
    R9=PHDA/AR                                                                 OUTP0207
    PDA=.0826*AR                                                               OUTP0208
    R10=PDA/AR                                                                 OUTP0209
    WRITE(5,130)UTDA,R4,SGDA,R5,ACDA,R6,XICDA,R7,AMDA,R8,PHDA,R9,PDA           OUTP0210
   1,R10                                                                       OUTP0211
130 FORMAT(' UPTAKES',T30,F10.0,F13.3/' STEERING GEAR & WINDLASS',T30,         OUTP0212
   1F10.0,F13.3/' A/C & FAN SPACES',T30,F10.0,F13.3/' I.C. SPACES',T30         OUTP0213
   2,F10.0,F13.3/' AUX MACHINERY SPACES',T30,F10.0,F13.3/' PILOT HOUSE         OUTP0214
   3,CHARTROOM & CIC',T30,F10.0,F13.3/' PASSAGES',T30,F10.0,F13.3)             OUTP0215
    ARE=AREADH+AREAHL                                                          OUTP0216
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      R1=ARE/AR                                                          OUTP0217
      HABSPC=XMFDA+CSDA+OSRDA+OHDA+CPODA+CPOHDA+CBDA+CHDA+CCDA           OUTP0218
      EXAR=AR-HABSPC-CCA-CSTDA-OSDA-WDA-RLDA-CLDA-UTDA-SGDA-ACDA-XICDA   OUTP0219
     1-AMDA-PHDA-PDA-ARE                                                 OUTP0220
      R2=EXAR/AR                                                         OUTP0221
      WRITE(5,131)ARE,R1,EXAR,R2                                         OUTP0222
  131 FORMAT(' INPUT AREA',T30,F10.0,F13.3/' EXCESS AREA',T30,F10.0,F13. OUTP0223
     13/)                                                                OUTP0224
      WRITE(5,132)                                                       OUTP0225
  132 FORMAT(/' CREW SPECIAL INCLUDES SICKBAY,BARBERSHOP,MOVIE LOCKER, L OUTP0226
     1AUNDRY,AND SHIPS STORE'////)                                       OUTP0227
      HABSPC=HABSPC*8.5                                                  OUTP0228
      COEF1=HABSPC/(NOFF+NCPO+NENL)                                      OUTP0229
      COEF2=WTG2/SHPM                                                    OUTP0230
      COEF3=VMB/SHPM                                                     OUTP0231
      COEF4=WTG1/ENCVOL                                                  OUTP0232
      COEF5=WFULLD/ENCVOL                                                OUTP0233
      COEF6=WLSHIP/ENCVOL                                                OUTP0234
      COEF7=CSTG4/TOTCST                                                 OUTP0235
      COEF8=CSTG7/TOTCST                                                 OUTP0236
      COEF9=CFULLD/DAVG                                                  OUTP0237
      WRITE(5,133)COEF1,COEF2,COEF3,COEF4,COEF5,COEF6,COEF7,COEF8,COEF9  OUTP0238
  133 FORMAT(' HAB VOL/MAN = ',F10.1,' CUFT/MAN'/' GR2WT/HP = ',F6.4,    OUTP0239
     1' TONS/HP'/' MACH ROOM VOL/HP = ',F7.4,' CUFT/HP'/' GR1WT/ENCVOL = OUTP0240
     2 ',F7.5,' TONS/CUFT'/' WFULLD/ENCVOL = ',F7.5,' TONS/CUFT'/' WLSHI OUTP0241
     3P/ENCVOL = ',F7.5,' TONS/CUFT'/' GR4COST/TOTCOST = ',F6.3/' GR7COS OUTP0242
     4T/TOTCOST = ',F6.3/' VCG/DAVG = ',F6.3///)                         OUTP0243
      RETURN                                                             OUTP0244
      END                                                                OUTP0245
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# APPENDIX D

## $C_r$ ARRAY

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .21 | .21 | .21 | .21 | .21 | .29 | .60 | 1.15 | 1.77 | 2.19 | 2.38 | 2.40 | 2.38 | 2.30 | 2.20 | 2.10 |
| .20 | .20 | .20 | .20 | .20 | .25 | .49 | .97 | 1.55 | 1.94 | 2.13 | 2.20 | 2.18 | 2.11 | 2.03 | 1.92 |
| .20 | .20 | .21 | .21 | .22 | .26 | .46 | .88 | 1.38 | 1.73 | 1.91 | 2.00 | 2.00 | 1.98 | 1.91 | 1.86 |
| .22 | .22 | .22 | .22 | .22 | .26 | .37 | .75 | 1.20 | 1.57 | 1.8 | 1.98 | 1.89 | 1.85 | 1.79 | 1.70 |
| .22 | .22 | .22 | .22 | .24 | .30 | .40 | .71 | 1.12 | 1.47 | 1.68 | 1.75 | 1.77 | 1.73 | 1.68 | 1.60 |
| .22 | .22 | .22 | .22 | .29 | .38 | .41 | .65 | 1.06 | 1.43 | 1.63 | 1.71 | 1.72 | 1.70 | 1.66 | 1.59 |
| .23 | .23 | .23 | .25 | .32 | .45 | .48 | .65 | 1.03 | 1.37 | 1.57 | 1.66 | 1.69 | 1.68 | 1.62 | 1.56 |
| .23 | .23 | .23 | .24 | .38 | .54 | .59 | .73 | 1.07 | 1.37 | 1.54 | 1.64 | 1.67 | 1.66 | 1.60 | 1.53 |
| .23 | .23 | .23 | .27 | .43 | .70 | .74 | .80 | 1.10 | 1.38 | 1.54 | 1.63 | 1.68 | 1.67 | 1.60 | 1.52 |
| .24 | .24 | .24 | .30 | .50 | .82 | .88 | .88 | 1.15 | 1.40 | 1.56 | 1.63 | 1.66 | 1.63 | 1.60 | 1.52 |
| .23 | .23 | .23 | .33 | .53 | .94 | 1.05 | .98 | 1.19 | 1.41 | 1.55 | 1.63 | 1.67 | 1.65 | 1.60 | 1.55 |
| .24 | .24 | .24 | .40 | .63 | 1.11 | 1.21 | 1.13 | 1.28 | 1.43 | 1.57 | 1.63 | 1.65 | 1.65 | 1.60 | 1.56 |
| .25 | .25 | .26 | .35 | .41 | .47 | 1.03 | 2.23 | 3.73 | 4.84 | 5.40 | 5.53 | 5.51 | 5.39 | 5.07 | 4.53 |
| .25 | .27 | .28 | .31 | .38 | .43 | .89 | 1.90 | 3.29 | 4.43 | 5.05 | 5.25 | 5.26 | 5.12 | 4.83 | 4.37 |
| .26 | .26 | .27 | .30 | .37 | .42 | .82 | 1.74 | 3.00 | 4.16 | 4.80 | 5.02 | 5.05 | 4.90 | 4.60 | 4.22 |
| .28 | .28 | .28 | .30 | .40 | .47 | .73 | 1.54 | 2.71 | 3.84 | 4.55 | 4.80 | 4.80 | 4.68 | 4.40 | 4.10 |
| .28 | .28 | .28 | .30 | .45 | .60 | .78 | 1.45 | 2.55 | 3.65 | 4.33 | 4.58 | 4.60 | 4.48 | 4.24 | 3.92 |
| .28 | .28 | .28 | .32 | .51 | .77 | .88 | 1.40 | 2.45 | 3.48 | 4.12 | 4.38 | 4.39 | 4.30 | 4.10 | 3.85 |
| .28 | .28 | .28 | .37 | .59 | 1.00 | 1.03 | 1.41 | 2.34 | 3.33 | 3.90 | 4.17 | 4.20 | 4.13 | 3.95 | 3.80 |
| .28 | .28 | .28 | .40 | .68 | 1.23 | 1.20 | 1.54 | 2.38 | 3.28 | 3.81 | 4.04 | 4.10 | 4.02 | 3.86 | 3.62 |
| .30 | .30 | .30 | .43 | .77 | 1.48 | 1.49 | 1.70 | 2.41 | 3.19 | 3.73 | 3.97 | 3.99 | 3.95 | 3.81 | 3.60 |
| .28 | .29 | .32 | .51 | .89 | 1.72 | 1.83 | 1.89 | 2.46 | 3.23 | 3.69 | 3.90 | 3.95 | 3.90 | 3.79 | 3.64 |
| .28 | .28 | .32 | .60 | .98 | 1.97 | 2.10 | 2.07 | 2.52 | 3.24 | 3.68 | 3.87 | 3.92 | 3.89 | 3.78 | 3.61 |
| .30 | .30 | .37 | .70 | 1.11 | 2.22 | 2.44 | 2.28 | 2.64 | 3.30 | 3.68 | 3.87 | 3.93 | 3.90 | 3.77 | 3.60 |
| .25 | .25 | .25 | .27 | .28 | .34 | .66 | 1.20 | 1.73 | 2.18 | 2.40 | 2.45 | 2.44 | 2.39 | 2.30 | 2.17 |
| .25 | .25 | .25 | .32 | .38 | .42 | .69 | 1.10 | 1.60 | 2.06 | 2.28 | 2.35 | 2.32 | 2.25 | 2.17 | 2.11 |
| .26 | .26 | .27 | .39 | .46 | .48 | .66 | 1.02 | 1.46 | 1.94 | 2.13 | 2.17 | 2.17 | 2.13 | 2.08 | 2.00 |
| .27 | .27 | .27 | .40 | .51 | .51 | .69 | .97 | 1.38 | 1.83 | 2.03 | 2.10 | 2.09 | 2.04 | 1.96 | 1.93 |
| .28 | .28 | .28 | .42 | .57 | .62 | .67 | .88 | 1.32 | 1.71 | 1.90 | 1.96 | 1.97 | 1.95 | 1.90 | 1.86 |
| .30 | .30 | .30 | .43 | .58 | .68 | .71 | .89 | 1.29 | 1.63 | 1.81 | 1.90 | 1.92 | 1.90 | 1.86 | 1.80 |
| .30 | .30 | .31 | .45 | .59 | .70 | .76 | .90 | 1.23 | 1.58 | 1.77 | 1.83 | 1.87 | 1.85 | 1.80 | 1.73 |
| .30 | .31 | .32 | .42 | .60 | .77 | .81 | .90 | 1.20 | 1.54 | 1.72 | 1.79 | 1.80 | 1.80 | 1.74 | 1.70 |
| .33 | .33 | .33 | .40 | .62 | .85 | .90 | .95 | 1.19 | 1.50 | 1.70 | 1.75 | 1.76 | 1.74 | 1.70 | 1.65 |
| .35 | .35 | .36 | .40 | .63 | .90 | 1.00 | 1.02 | 1.25 | 1.53 | 1.67 | 1.75 | 1.77 | 1.76 | 1.70 | 1.63 |
| .34 | .34 | .35 | .40 | .64 | 1.05 | 1.17 | 1.12 | 1.25 | 1.53 | 1.69 | 1.74 | 1.76 | 1.75 | 1.70 | 1.62 |
| .35 | .35 | .36 | .40 | .65 | 1.20 | 1.37 | 1.22 | 1.25 | 1.53 | 1.68 | 1.74 | 1.76 | 1.75 | 1.70 | 1.61 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .29 | .30 | .32 | .50 | .57 | .60 | 1.13 | 2.19 | 3.60 | 4.90 | 5.56 | 5.80 | 5.76 | 5.57 | 5.25 | 5.05 |
| .30 | .30 | .31 | .51 | .62 | .60 | 1.04 | 1.93 | 3.29 | 4.57 | 5.31 | 5.50 | 5.50 | 5.40 | 5.20 | 4.80 |
| .33 | .33 | .33 | .52 | .66 | .66 | .97 | 1.75 | 3.06 | 4.27 | 5.00 | 5.30 | 5.30 | 5.25 | 5.10 | 4.90 |
| .32 | .32 | .33 | .52 | .68 | .71 | .96 | 1.61 | 2.80 | 4.04 | 4.72 | 5.00 | 5.00 | 5.00 | 4.90 | 4.70 |
| .34 | .34 | .34 | .54 | .73 | .82 | 1.00 | 1.60 | 2.68 | 3.80 | 4.42 | 4.71 | 4.80 | 4.77 | 4.64 | 4.40 |
| .34 | .34 | .37 | .55 | .78 | .98 | 1.15 | 1.65 | 2.57 | 3.62 | 4.26 | 4.40 | 4.50 | 4.50 | 4.40 | 4.20 |
| .37 | .38 | .40 | .57 | .83 | 1.17 | 1.34 | 1.70 | 2.55 | 3.52 | 4.17 | 4.45 | 4.50 | 4.55 | 4.50 | 4.30 |
| .38 | .38 | .40 | .58 | .88 | 1.35 | 1.60 | 1.85 | 2.55 | 3.46 | 4.08 | 4.34 | 4.42 | 4.42 | 4.35 | 4.20 |
| .38 | .38 | .41 | .59 | .94 | 1.60 | 1.85 | 2.02 | 2.54 | 3.40 | 4.05 | 4.41 | 4.55 | 4.50 | 4.30 | 4.00 |
| .40 | .40 | .48 | .63 | 1.02 | 1.82 | 2.07 | 2.21 | 2.70 | 3.44 | 4.03 | 4.27 | 4.35 | 4.25 | 4.10 | 3.80 |
| .40 | .40 | .48 | .70 | 1.11 | 2.07 | 2.40 | 2.45 | 2.80 | 3.48 | 4.04 | 4.28 | 4.35 | 4.30 | 4.10 | 3.80 |
| .41 | .41 | .54 | .80 | 1.24 | 2.30 | 2.70 | 2.71 | 2.98 | 3.60 | 4.05 | 4.26 | 4.32 | 4.30 | 4.10 | 3.80 |
| .30 | .30 | .30 | .41 | .48 | .47 | .64 | 1.20 | 1.87 | 2.35 | 2.68 | 2.80 | 2.80 | 2.76 | 2.70 | 2.60 |
| .33 | .33 | .33 | .42 | .48 | .47 | .65 | 1.09 | 1.63 | 2.13 | 2.45 | 2.59 | 2.60 | 2.58 | 2.50 | 2.40 |
| .35 | .35 | .35 | .43 | .46 | .44 | .59 | .93 | 1.48 | 2.01 | 2.26 | 2.37 | 2.39 | 2.37 | 2.31 | 2.24 |
| .37 | .37 | .37 | .41 | .47 | .45 | .58 | .87 | 1.34 | 1.82 | 2.06 | 2.17 | 2.20 | 2.20 | 2.13 | 2.06 |
| .40 | .40 | .40 | .43 | .48 | .49 | .59 | .82 | 1.24 | 1.65 | 1.90 | 2.00 | 2.06 | 2.05 | 2.00 | 1.91 |
| .40 | .40 | .40 | .42 | .48 | .54 | .63 | .83 | 1.23 | 1.60 | 1.80 | 1.93 | 1.97 | 1.97 | 1.91 | 1.78 |
| .42 | .42 | .42 | .45 | .52 | .61 | .73 | .81 | 1.18 | 1.53 | 1.74 | 1.87 | 1.93 | 1.90 | 1.85 | 1.73 |
| .42 | .42 | .42 | .44 | .54 | .69 | .81 | .90 | 1.16 | 1.53 | 1.77 | 1.89 | 1.90 | 1.89 | 1.80 | 1.70 |
| .45 | .45 | .45 | .50 | .58 | .80 | .93 | 1.00 | 1.18 | 1.52 | 1.73 | 1.83 | 1.88 | 1.85 | 1.78 | 1.69 |
| .47 | .47 | .47 | .56 | .67 | .90 | 1.05 | 1.09 | 1.23 | 1.53 | 1.74 | 1.85 | 1.88 | 1.84 | 1.77 | 1.67 |
| .48 | .48 | .48 | .62 | .70 | 1.00 | 1.20 | 1.20 | 1.30 | 1.52 | 1.71 | 1.85 | 1.87 | 1.82 | 1.74 | 1.69 |
| .49 | .49 | .49 | .68 | .73 | 1.10 | 1.34 | 1.33 | 1.37 | 1.52 | 1.71 | 1.84 | 1.87 | 1.80 | 1.72 | 1.70 |
| .35 | .35 | .40 | .53 | .67 | .65 | 1.13 | 2.30 | 3.72 | 5.00 | 5.95 | 6.40 | 6.50 | 6.40 | 6.10 | 5.50 |
| .38 | .38 | .42 | .54 | .65 | .63 | 1.00 | 1.95 | 3.40 | 4.67 | 5.50 | 5.80 | 5.90 | 5.80 | 5.50 | 5.10 |
| .41 | .41 | .43 | .53 | .60 | .63 | .89 | 1.78 | 3.10 | 4.33 | 5.10 | 5.35 | 5.40 | 5.30 | 5.10 | 4.90 |
| .43 | .43 | .45 | .53 | .64 | .70 | .91 | 1.70 | 2.90 | 4.07 | 4.79 | 5.00 | 5.10 | 5.10 | 4.90 | 4.70 |
| .45 | .45 | .45 | .53 | .68 | .81 | .97 | 1.62 | 2.73 | 3.87 | 4.60 | 4.95 | 5.10 | 5.00 | 4.90 | 4.60 |
| .45 | .45 | .47 | .53 | .72 | .91 | 1.15 | 1.59 | 2.62 | 3.75 | 4.48 | 4.90 | 5.00 | 5.00 | 4.90 | 4.50 |
| .48 | .49 | .50 | .56 | .78 | 1.10 | 1.35 | 1.78 | 2.64 | 3.70 | 4.40 | 4.74 | 4.80 | 4.75 | 4.60 | 4.25 |
| .48 | .48 | .50 | .56 | .84 | 1.30 | 1.60 | 1.92 | 2.63 | 3.65 | 4.34 | 4.65 | 4.70 | 4.58 | 4.40 | 4.10 |
| .52 | .52 | .53 | .63 | .93 | 1.53 | 1.85 | 2.13 | 2.77 | 3.63 | 4.29 | 4.61 | 4.70 | 4.55 | 4.35 | 4.00 |
| .53 | .54 | .56 | .70 | 1.01 | 1.78 | 2.10 | 2.32 | 2.85 | 3.61 | 4.24 | 4.55 | 4.60 | 4.50 | 4.25 | 3.90 |
| .55 | .55 | .58 | .79 | 1.16 | 2.05 | 2.40 | 2.57 | 3.00 | 3.67 | 4.23 | 4.53 | 4.55 | 4.40 | 4.10 | 3.80 |
| .58 | .58 | .66 | .90 | 1.30 | 2.30 | 2.73 | 2.83 | 3.20 | 3.70 | 4.22 | 4.50 | 4.45 | 4.25 | 4.00 | 3.70 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| .31 | .31 | .33 | .50 | .57 | .64 | 1.50 | 3.40 | 5.65 |
| .31 | .31 | .34 | .43 | .52 | .60 | 1.20 | 1.80 | 5.10 |
| .30 | .30 | .32 | .38 | .48 | .60 | 1.12 | 2.60 | 4.60 |
| .33 | .33 | .34 | .39 | .52 | .78 | 1.07 | 2.23 | 4.17 |
| .33 | .33 | .35 | .40 | .58 | .86 | 1.13 | 2.10 | 3.90 |
| .34 | .34 | .34 | .42 | .67 | 1.14 | 1.30 | 2.05 | 3.83 |
| .34 | .34 | .35 | .46 | .79 | 1.45 | 1.55 | 2.10 | 3.67 |
| .34 | .34 | .37 | .50 | .89 | 1.76 | 1.84 | 2.26 | 3.65 |
| .34 | .34 | .38 | .57 | 1.00 | 2.09 | 2.23 | 2.50 | 3.68 |
| .33 | .33 | .40 | .65 | 1.15 | 2.43 | 2.69 | 2.82 | 3.80 |
| .34 | .34 | .41 | .74 | 1.29 | 2.75 | 3.18 | 3.18 | 3.90 |
| .35 | .36 | .47 | .85 | 1.45 | 3.12 | 3.76 | 3.63 | 4.10 |
| .35 | .35 | .40 | .60 | .72 | .85 | 2.00 | 4.70 | 7.70 |
| .35 | .36 | .39 | .50 | .60 | .74 | 1.54 | 3.65 | 7.00 |
| .35 | .35 | .38 | .46 | .57 | .73 | 1.37 | 3.30 | 6.30 |
| .38 | .38 | .40 | .47 | .61 | .83 | 1.37 | 2.85 | 5.70 |
| .38 | .38 | .40 | .48 | .70 | 1.10 | 1.49 | 2.72 | 4.32 |
| .38 | .38 | .40 | .51 | .83 | 1.45 | 1.70 | 2.65 | 5.20 |
| .38 | .38 | .42 | .55 | .97 | 1.80 | 2.00 | 2.70 | 4.00 |
| .39 | .39 | .43 | .62 | 1.10 | 2.18 | 2.43 | 2.97 | 5.10 |
| .40 | .40 | .46 | .69 | 1.20 | 2.62 | 2.95 | 3.30 | 5.00 |
| .40 | .40 | .48 | .77 | 1.40 | 3.07 | 3.56 | 3.73 | 5.15 |
| .40 | .40 | .50 | .86 | 1.55 | 3.50 | 4.23 | 4.23 | 5.30 |
| .40 | .42 | .57 | .98 | 1.71 | 4.00 | 5.03 | 4.89 | 5.60 |
| .40 | .41 | .48 | .70 | .88 | 1.10 | 2.60 | 6.00 | 9.70 |
| .42 | .42 | .46 | .60 | .72 | .90 | 1.90 | 4.45 | 9.00 |
| .42 | .42 | .43 | .52 | .67 | .83 | 1.60 | 4.15 | 8.10 |
| .42 | .42 | .45 | .52 | .70 | .94 | 1.57 | 3.80 | 7.20 |
| .43 | .43 | .46 | .55 | .81 | 1.26 | 1.73 | 3.40 | 6.80 |
| .44 | .44 | .48 | .58 | .95 | 1.70 | 2.00 | 3.45 | 6.50 |
| .45 | .45 | .50 | .63 | 1.10 | 2.11 | 2.45 | 3.33 | 6.35 |
| .45 | .45 | .50 | .70 | 1.26 | 2.63 | 3.05 | 3.64 | 6.15 |
| .47 | .47 | .53 | .78 | 1.40 | 3.10 | 3.70 | 4.10 | 5.30 |
| .46 | .48 | .57 | .86 | 1.58 | 3.70 | 4.46 | 4.64 | 6.40 |
| .45 | .46 | .58 | .95 | 1.75 | 4.20 | 5.33 | 5.28 | 6.80 |
| .47 | .49 | .68 | 1.08 | 1.93 | 4.90 | 6.30 | 6.00 | 7.05 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| .36 | .36 | .37 | .66 | .78 | .86 | 1.60 | 3.40 | 6.10 |
| .35 | .35 | .38 | .62 | .76 | .82 | 1.40 | 2.90 | 5.10 |
| .39 | .38 | .39 | .60 | .77 | .81 | 1.25 | 2.55 | 4.75 |
| .38 | .38 | .40 | .60 | .78 | .84 | 1.23 | 2.45 | 4.45 |
| .40 | .40 | .42 | .60 | .82 | 1.00 | 1.30 | 2.34 | 4.20 |
| .40 | .40 | .43 | .62 | .89 | 1.25 | 1.50 | 2.36 | 3.97 |
| .42 | .42 | .44 | .64 | .99 | 1.52 | 1.80 | 2.50 | 3.83 |
| .44 | .44 | .47 | .68 | 1.08 | 1.83 | 2.20 | 2.70 | 3.90 |
| .43 | .43 | .49 | .72 | 1.20 | 2.17 | 2.63 | 3.01 | 3.98 |
| .45 | .46 | .55 | .79 | 1.35 | 2.50 | 3.05 | 3.34 | 4.20 |
| .46 | .46 | .58 | .94 | 1.50 | 2.85 | 3.54 | 3.75 | 4.45 |
| .48 | .49 | .67 | 1.07 | 1.65 | 3.24 | 4.04 | 4.18 | 4.80 |
| .41 | .41 | .45 | .76 | .95 | 1.07 | 2.07 | 4.75 | 9.20 |
| .42 | .42 | .45 | .72 | .86 | .98 | 1.80 | 3.95 | 7.00 |
| .44 | .44 | .47 | .68 | .83 | .96 | 1.58 | 3.50 | 6.50 |
| .43 | .43 | .47 | .65 | .82 | .97 | 1.52 | 3.13 | 6.20 |
| .44 | .45 | .48 | .64 | .89 | 1.15 | 1.58 | 3.00 | 5.54 |
| .47 | .47 | .50 | .66 | .95 | 1.48 | 1.83 | 2.94 | 5.20 |
| .47 | .47 | .52 | .70 | 1.05 | 1.83 | 2.36 | 3.12 | 5.03 |
| .50 | .50 | .54 | .73 | 1.18 | 2.20 | 2.77 | 3.44 | 5.32 |
| .50 | .51 | .58 | .80 | 1.37 | 2.67 | 3.30 | 3.80 | 5.40 |
| .53 | .53 | .62 | .89 | 1.50 | 3.10 | 3.90 | 4.27 | 5.70 |
| .53 | .53 | .68 | 1.04 | 1.73 | 3.55 | 4.62 | 4.90 | 6.17 |
| .55 | .56 | .78 | 1.22 | 1.90 | 4.00 | 5.30 | 5.60 | 6.60 |
| .47 | .47 | .53 | .87 | 1.10 | 1.29 | 2.73 | 6.10 | 12.00 |
| .48 | .48 | .52 | .81 | .97 | 1.17 | 2.25 | 4.90 | 9.00 |
| .50 | .50 | .54 | .75 | .90 | 1.08 | 1.90 | 4.50 | 8.20 |
| .52 | .52 | .54 | .72 | .87 | 1.07 | 1.80 | 3.80 | 7.50 |
| .52 | .52 | .56 | .70 | .93 | 1.25 | 1.87 | 3.60 | 6.70 |
| .53 | .53 | .57 | .73 | 1.01 | 1.69 | 2.21 | 3.45 | 6.25 |
| .55 | .55 | .58 | .76 | 1.13 | 2.13 | 2.74 | 3.65 | 6.10 |
| .53 | .53 | .62 | .80 | 1.28 | 2.58 | 3.32 | 4.04 | 6.75 |
| .56 | .57 | .66 | .87 | 1.46 | 3.09 | 3.94 | 4.55 | 6.80 |
| .58 | .58 | .73 | .96 | 1.63 | 3.60 | 4.74 | 5.17 | 7.20 |
| .58 | .58 | .77 | 1.10 | 1.84 | 4.17 | 5.74 | 5.95 | 7.90 |
| .60 | .62 | .88 | 1.31 | 2.07 | 4.70 | 6.45 | 7.05 | 8.40 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| .42 | .42 | .49 | .70 | .88 | .95 | 1.68 | 3.43 | 6.00 |
| .46 | .46 | .50 | .67 | .81 | .88 | 1.42 | 2.91 | 5.40 |
| .46 | .46 | .51 | .66 | .77 | .85 | 1.30 | 2.65 | 4.95 |
| .50 | .50 | .54 | .67 | .77 | .96 | 1.28 | 2.44 | 4.45 |
| .50 | .50 | .53 | .64 | .81 | 1.08 | 1.38 | 2.33 | 4.10 |
| .52 | .52 | .54 | .63 | .88 | 1.24 | 1.60 | 2.45 | 4.05 |
| .53 | .55 | .57 | .65 | .97 | 1.47 | 1.87 | 2.53 | 4.10 |
| .53 | .53 | .58 | .66 | 1.08 | 1.75 | 2.25 | 2.90 | 4.15 |
| .58 | .58 | .62 | .73 | 1.24 | 2.10 | 2.65 | 3.17 | 4.30 |
| .60 | .60 | .67 | .84 | 1.31 | 2.48 | 3.10 | 3.53 | 4.50 |
| .62 | .62 | .68 | .95 | 1.48 | 2.86 | 3.60 | 3.96 | 4.73 |
| .63 | .63 | .77 | 1.10 | 1.64 | 3.27 | 4.13 | 4.38 | 5.07 |
| .48 | .50 | .56 | .84 | 1.09 | 1.28 | 2.20 | 4.63 | 8.20 |
| .52 | .52 | .60 | .82 | .99 | 1.16 | 1.90 | 4.10 | 7.10 |
| .55 | .55 | .59 | .78 | .92 | 1.10 | 1.72 | 3.61 | 6.50 |
| .55 | .55 | .61 | .80 | .92 | 1.18 | 1.68 | 3.30 | 5.95 |
| .57 | .57 | .62 | .73 | .96 | 1.33 | 1.77 | 3.10 | 5.50 |
| .58 | .58 | .62 | .73 | 1.01 | 1.51 | 2.05 | 3.13 | 5.30 |
| .62 | .60 | .65 | .76 | 1.11 | 1.76 | 2.40 | 3.30 | 5.20 |
| .62 | .62 | .68 | .78 | 1.25 | 2.10 | 2.80 | 3.60 | 5.30 |
| .65 | .65 | .73 | .85 | 1.40 | 2.50 | 3.30 | 3.98 | 5.55 |
| .67 | .67 | .76 | .96 | 1.58 | 2.95 | 3.83 | 4.44 | 5.80 |
| .67 | .67 | .80 | 1.09 | 1.75 | 3.45 | 4.43 | 5.00 | 6.15 |
| .72 | .71 | .85 | 1.23 | 1.94 | 3.90 | 5.15 | 5.63 | 6.54 |
| .55 | .56 | .65 | 1.00 | 1.32 | 1.60 | 2.86 | 5.90 | 10.40 |
| .58 | .58 | .65 | .94 | 1.16 | 1.35 | 2.48 | 5.15 | 8.80 |
| .61 | .60 | .67 | .90 | 1.07 | 1.30 | 2.20 | 4.50 | 7.90 |
| .62 | .62 | .70 | .87 | 1.05 | 1.36 | 2.10 | 4.05 | 7.40 |
| .64 | .64 | .70 | .83 | 1.10 | 1.53 | 2.18 | 3.80 | 6.90 |
| .64 | .64 | .73 | .81 | 1.15 | 1.79 | 2.43 | 3.80 | 6.50 |
| .68 | .70 | .75 | .87 | 1.25 | 2.13 | 2.85 | 3.90 | 6.30 |
| .68 | .68 | .77 | .87 | 1.37 | 2.55 | 3.35 | 4.27 | 6.20 |
| .70 | .72 | .82 | .98 | 1.57 | 3.05 | 3.98 | 4.80 | 6.50 |
| .73 | .73 | .84 | 1.09 | 1.77 | 3.60 | 4.65 | 5.30 | 6.80 |
| .74 | .75 | .90 | 1.20 | 2.00 | 4.10 | 5.35 | 5.90 | 7.20 |
| .77 | .77 | .95 | 1.34 | 2.20 | 4.30 | 5.85 | 6.40 | 8.6 |

| | | | | | |
|---|---|---|---|---|---|
| .44 | .45 | .53 | .82 | 1.08 | 1.31 |
| .46 | .47 | .51 | .67 | .86 | 1.04 |
| .47 | .47 | .48 | .59 | .77 | .94 |
| .48 | .48 | .50 | .60 | .80 | 1.03 |
| .50 | .49 | .51 | .63 | .90 | 1.37 |
| .50 | .50 | .53 | .65 | 1.07 | 1.87 |
| .50 | .50 | .55 | .70 | 1.23 | 2.43 |
| .50 | .50 | .57 | .76 | 1.40 | 3.06 |
| .52 | .52 | .60 | .83 | 1.55 | 3.60 |
| .52 | .53 | .65 | .93 | 1.74 | 4.15 |
| .52 | .53 | .68 | 1.03 | 1.93 | 4.90 |
| .52 | .56 | .76 | 1.18 | 2.10 | 4.80 |
| .52 | .52 | .61 | 1.05 | 1.32 | 1.57 |
| .53 | .54 | .63 | .94 | 1.10 | 1.32 |
| .55 | .56 | .62 | .86 | 1.02 | 1.20 |
| .57 | .57 | .63 | .82 | .93 | 1.20 |
| .58 | .58 | .64 | .80 | 1.00 | 1.43 |
| .58 | .60 | .65 | .83 | 1.08 | 1.87 |
| .60 | .60 | .68 | .84 | 1.22 | 2.40 |
| .62 | .62 | .70 | .87 | 1.37 | 2.91 |
| .62 | .62 | .75 | .94 | 1.55 | 3.50 |
| .64 | .66 | .80 | 1.03 | 1.75 | 4.10 |
| .67 | .67 | .85 | 1.17 | 1.93 | 4.75 |
| .67 | .71 | .96 | 1.38 | 2.23 | 4.90 |
| .62 | .64 | .75 | 1.15 | 1.56 | 1.93 |
| .65 | .67 | .75 | 1.10 | 1.35 | 1.59 |
| .68 | .69 | .75 | 1.01 | 1.22 | 1.46 |
| .70 | .70 | .78 | .98 | 1.16 | 1.51 |
| .72 | .72 | .79 | .94 | 1.19 | 1.70 |
| .72 | .72 | .81 | .94 | 1.28 | 2.00 |
| .74 | .76 | .83 | .96 | 1.40 | 2.42 |
| .77 | .77 | .87 | 1.00 | 1.56 | 3.00 |
| .78 | .78 | .91 | 1.10 | 1.75 | 3.50 |
| .80 | .80 | .97 | 1.22 | 1.94 | 4.30 |
| .80 | .82 | 1.00 | 1.32 | 2.14 | 4.90 |
| .82 | .83 | 1.05 | 1.47 | 2.40 | 5.10 |

# APPENDIX E

## HULL GROUP WEIGHT CLASSIFICATION OF 1965

# NAVSHIPS HULL GROUP WEIGHT CLASSIFICATION OF 1965

## Group 1 - Hull Structure

100 - Shell Plating and Planking
101 - Longitudinal and Transverse Framing
102 - Inner Bottom
103 - Platforms and Flats Below Lowermost Continuous Deck
104 - Fourth and Lower Continuous Decks
105 - Third Deck
106 - Second Deck
107 - Main Deck and Hangar Deck
108 - Forecastle and Poop Decks
109 - Gallery Deck
110 - Flight Deck, Landing Platforms, Special Purpose Decks above Weather Deck
111 - Superstructure
112 - Foundations for Propulsion Plant Machinery
113 - Foundations for Auxiliaries and Other Equipment
114 - Structural Bulkheads
115 - Trunks and Enclosures
116 - Structural Sponsons
117 - Armor
118 - Aircraft Fuel Saddle Tank Structure
119 - Structural Castings, Forgings and Equivalent Weldments
120 - Sea Chests
121 - Ballast and Buoyancy Units, Fixed or Fluid
122 - Doors and Closures, Special Purpose
123 - Doors, Hatches, Manholes and Scuttles - Nonballistic
124 - Doors, Hatches, Manholes and Scuttles - Ballistic
125 - Kingposts and Support Frames
127 - Sonar Dome
128 - Masts, Towers, Tetrapods, and Service Platforms
150 - Welding, Riveting, and Fastenings
151 - Free Flooding Liquids

## Group 2 - Propulsion

200 - Boilers and Energy Converters (Non-Nuclear)
201 - Propulsion Units
202 - Main Condensers and Air Ejectors
203 - Shafting, Bearings, and Propellers
204 - Combustion Air Supply System
205 - Uptakes (Smoke Pipes)
206 - Propulsion Control Equipment (Non-Nuclear)
207 - Main Steam System
208 - Feedwater and Condensate System
209 - Circulating and Cooling Water Systems
210 - Fuel Oil Service System
211 - Lubricating Oil System
212 - Nuclear Steam Generators
213 - Reactors
214 - Reactor Coolant System
215 - Reactor Coolant Service Systems
216 - Reactor Plant Auxiliary Systems
217 - Nuclear Power Control and Instrumentation
218 - Radiation Shielding (Primary)
219 - Radiation Shielding (Secondary)
250 - Propulsion Repair Parts
251 - Propulsion Operating Fluids

## Group 3 - Electric Plant

300 - Electric Power Generation
301 - Power Distribution Switchboards
302 - Power Distribution System (Cable)
303 - Lighting System (Distribution and Fixtures)
350 - Electric Plant Repair Parts
351 - Electric Power Generator Fluids

## Group 4 - Communication and Control

400 - Navigation Equipment (Non-Electronic)
401 - Interior Communication Systems and Equipment
402 - Gun Fire Control System
403 - Countermeasure Systems (Non-Electronic)
404 - Electronic Countermeasure Systems (ECM)
405 - Missile Fire Control Systems
406 - ASW, Torpedo Fire Control Systems (Surface Ships)
407 - Torpedo Fire Control System (Submarines)
408 - Radar Systems
409 - Radio Communication Systems
410 - Electronic Navigation Systems
411 - Space Vehicle Electronic Tracking Systems
412 - Sonar Systems
413 - Electronic Tactical Data System
450 - Communication and Control Repair Parts
451 - Communication and Control Operating Fluids

## Group 5 - Auxiliary Systems

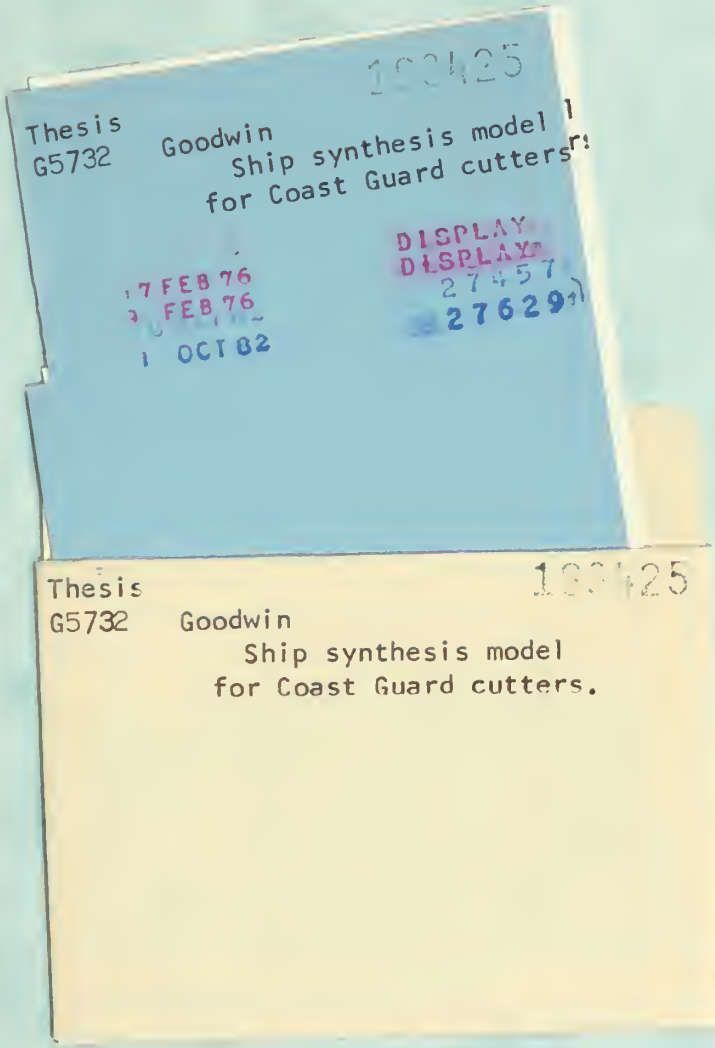
500 - Heating System
501 - Ventilation System
502 - Air Conditioning System
503 - Refrigerating Spaces, Plant, and Equipment
504 - Gasoline, HEAF, All Liquid Cargo Piping, Oxygen, Nitrogen, and Aviation Lubricating Oil Systems
505 - Plumbing Installations
506 - Firemain, Flushing, Sprinkler, Washdown, and Salt Water Service Systems
507 - Fire Extinguishing Systems
508 - Drainage, Ballast, Trimming, Heeling, and Stabilizer Tank Systems
509 - Fresh Water System
510 - Scuppers and Deck Drains
511 - Fuel and Diesel Oil Filling, Venting, Stowage and Transfer Systems
512 - Tank Heating Systems
513 - Compressed Air System
514 - Auxiliary Steam, Exhaust Steam, and Steam Drains
515 - Buoyancy Control System
516 - Miscellaneous Piping Systems
517 - Distilling Plant
518 - Steering Systems
519 - Rudders
520 - Mooring, Towing, Anchor and Aircraft Handling Systems and Deck Machinery
521 - Elevators, Moving Stairways, Stores Strikedown, and Stores Handling Equipment
522 - Operating Gear for Retracting and Elevating Units
523 - Aircraft Elevators
524 - Aircraft Arresting Gear, Barriers, and Barricades
525 - Catapults and Jet Blast Deflectors
527 - Diving Planes and Stabilizing Fins
528 - Replenishment at Sea and Cargo Handling
550 - Auxiliary Systems Repair Parts
551 - Auxiliary Systems Operating Fluids, Gases, and Stabilizer Fluids

## Group 6 - Outfit and Furnishings

600 - Hull Fittings
601 - Boats, Boat Stowage, and Handling
602 - Rigging and Canvas
603 - Ladders and Gratings
604 - Nonstructural Bulkheads and Nonstructural Doors
605 - Painting
606 - Deck Covering
607 - Hull Insulation
608 - Storerooms, Stowages and Lockers
609 - Equipment for Utility Spaces
610 - Equipment for Workshops, Laboratories, and Test Areas
611 - Equipment for Galley, Pantry, Scullery and Commissary
612 - Furnishings for Living Spaces
613 - Furnishings: Offices, Control Centers, Machinery Spaces
614 - Furnishings for Medical, Dental, and Pharmaceutical
615 - Radiation Shielding for Nuclear Support Facilities
650 - Outfit and Furnishings Repair Parts
651 - Outfit and Furnishings Operating Fluids

## Group 7 - Armament

700 - Guns and Gun Mounts
701 - Ammunition Handling Systems
702 - Ammunition Stowage
703 - Special Weapons, Handling and Stowage
704 - Rocket and Missile Launching Devices (Surface to Air, Surface to Surface, and Sub-Surface)
705 - Rocket and Missile Launching Devices (Antisubmarine Warfare)
706 - Rocket, Missile, and Components Handling Systems
707 - Rocket, Missile, and Components Stowage
708 - Torpedo Tubes
709 - Torpedo Handling and Stowage
710 - Mine Handling Systems and Stowage
711 - Small Arms and Pyrotechnic Stowage
712 - Air-Launched Weapons Handling Systems
713 - Air-Launched Weapons Stowage
720 - Cargo Munition Stowage
745 - General Arrangement - Armament Drawings
750 - Armament Repair Parts
751 - Armament Operating Fluids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